OVERSIGHT OF THE NETWORKING AND INFORMATION TECHNOLOGY RESEARCH AND DEVELOPMENT (NITRD) PROGRAM

HEARING

BEFORE THE

COMMITTEE ON SCIENCE AND TECHNOLOGY
HOUSE OF REPRESENTATIVES

ONE HUNDRED TENTH CONGRESS

SECOND SESSION

JULY 31, 2008

Serial No. 110–119

Printed for the use of the Committee on Science and Technology

Available via the World Wide Web: http://www.science.house.gov

U.S. GOVERNMENT PRINTING OFFICE

43–688PS WASHINGTON : 2008

For sale by the Superintendent of Documents, U.S. Government Printing Office
Internet: bookstore.gpo.gov Phone: toll free (866) 512–1800; DC area (202) 512–1800
Fax: (202) 512–2104 Mail: Stop IDCC, Washington, DC 20402–0001

COMMITTEE ON SCIENCE AND TECHNOLOGY

HON. BART GORDON, Tennessee, *Chairman*

JERRY F. COSTELLO, Illinois
EDDIE BERNICE JOHNSON, Texas
LYNN C. WOOLSEY, California
MARK UDALL, Colorado
DAVID WU, Oregon
BRIAN BAIRD, Washington
BRAD MILLER, North Carolina
DANIEL LIPINSKI, Illinois
NICK LAMPSON, Texas
GABRIELLE GIFFORDS, Arizona
JERRY MCNERNEY, California
LAURA RICHARDSON, California
PAUL KANJORSKI, Pennsylvania
STEVEN R. ROTHMAN, New Jersey
JIM MATHESON, Utah
MIKE ROSS, Arkansas
BEN CHANDLER, Kentucky
RUSS CARNAHAN, Missouri
CHARLIE MELANCON, Louisiana
BARON P. HILL, Indiana
HARRY E. MITCHELL, Arizona
CHARLES A. WILSON, Ohio
ANDRÉ CARSON, Indiana

RALPH M. HALL, Texas
F. JAMES SENSENBRENNER JR., Wisconsin
LAMAR S. SMITH, Texas
DANA ROHRABACHER, California
ROSCOE G. BARTLETT, Maryland
VERNON J. EHLERS, Michigan
FRANK D. LUCAS, Oklahoma
JUDY BIGGERT, Illinois
W. TODD AKIN, Missouri
TOM FEENEY, Florida
RANDY NEUGEBAUER, Texas
BOB INGLIS, South Carolina
DAVID G. REICHERT, Washington
MICHAEL T. MCCAUL, Texas
MARIO DIAZ-BALART, Florida
PHIL GINGREY, Georgia
BRIAN P. BILBRAY, California
ADRIAN SMITH, Nebraska
PAUL C. BROUN, Georgia
VACANCY

CONTENTS

July 31, 2008

OVERSIGHT OF THE NETWORKING AND INFORMATION TECHNOLOGY RESEARCH AND DEVELOPMENT (NITRD) PROGRAM

THURSDAY, JULY 31, 2008

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE AND TECHNOLOGY,
Washington, DC.

The Committee met, pursuant to call, at 10:03 a.m., in Room 2318 of the Rayburn House Office Building, Hon. Bart Gordon [Chairman of the Committee] presiding.

BART GORDON, TENNESSEE
CHAIRMAN

RALPH M. HALL, TEXAS
RANKING MEMBER

U.S. HOUSE OF REPRESENTATIVES

COMMITTEE ON SCIENCE AND TECHNOLOGY

SUITE 2321 RAYBURN HOUSE OFFICE BUILDING
WASHINGTON, DC 20515-6301
(202) 225-6375
http://science.house.gov

Hearing on:

Oversight of the Networking and Information Technology Research and Development (NITRD) Program

Thursday, July 31, 2008
10:00 a.m. – 12:00 p.m.
2318 Rayburn House Office Building
Washington, D.C.

WITNESS LIST

Dr. Chris L. Greer
Director, National Coordination Office for Networking and Information Technology Research and Development (NCO/NITRD)

Dr. Daniel A. Reed
Director, Scalable and Multicore Computing, Microsoft Corporation

Dr. Craig Stewart
Associate Dean, Research Technologies, Indiana University; representing the Coalition for Academic Scientific Computation (CASC)

Mr. Don C. Winter
Vice President, Engineering and Information Technology, Phantom Works, the Boeing Company

HEARING CHARTER

COMMITTEE ON SCIENCE AND TECHNOLOGY U.S. HOUSE OF REPRESENTATIVES

Oversight of the Networking and Information Technology Research Development (NITRD) Program

THURSDAY, JULY 31, 2008
10:00 A.M.–12:00 P.M.
2318 RAYBURN HOUSE OFFICE BUILDING

1. Purpose

On Thursday, July 31, 2008, the Committee on Science and Technology will hold an oversight hearing to review the multi-agency, coordinated Networking and Information Technology Research and Development (NITRD) program. The hearing will examine the current program in light of the recent assessment of the President's Council of Advisors on Science and Technology (PCAST) and explore whether additional legislative adjustments to the program are needed.

2. Witnesses

Dr. Chris L. Greer, Director, National Coordination Office for Networking and Information Technology Research and Development (NCO/NITRD).

The NCO/NITRD provides staff support for the subcommittees and working groups of the National Science and Technology Council that are responsible for planning and coordinating the NITRD program and serves as the interface with the public for the NITRD program.

Dr. Daniel A. Reed, Director of Scalable and Multicore Computing, Microsoft.

Dr. Reed is a member of PCAST and of the PCAST committee that carried out the recent assessment of the NITRD program. He previously served as a member of the President's Information Technology Advisory Committee.

Dr. Craig Stewart, Associate Dean, Research Technologies, Indiana University, and representing the Coalition for Academic Scientific Computation (CASC).

CASC members are academic and government computer centers that support computational research in science and engineering and that are involved in applications requiring high-performance computers and networks and advanced software development.

Mr. Don C. Winter, Vice President—Engineering and Information Technology, Phantom Works, the Boeing Company.

Mr. Winter has been involved in a planning effort with others from industry and academia to develop a research agenda and roadmap in the area of cyber-physical systems, which is one of the key research areas the PCAST assessment calls out for increased funding under the NITRD program.

3. Overarching Questions

- Do the objectives of the NITRD program address the most important information technology R&D issues? Are the R&D objectives prioritized and are the resources allocated appropriately to achieve the objectives?
- Are there significant research opportunities that the NITRD program is not pursuing?
- Is the overall funding level for the NITRD program adequate for maintaining U.S. leadership in this important technology field?
- Are any changes needed to the planning, coordination, and prioritization mechanisms of the NITRD program in order to make them function more effectively?
- Does the research community—both academe and industry—have a voice in influencing the research priorities under the NITRD program? Are improvements needed in the external advisory process for the NITRD program?

- Do the recommendations of the recent PCAST assessment of the NITRD program encompass all of the key issues necessary to make the NITRD program more effective and relevant to research needs and opportunities in information technology?

4. Background

NITRD Program

The *High-Performance Computing Act of 1991* (P.L. 102–194), which the Science and Technology Committee was instrumental in enacting, authorized a multi-agency research program, called the High Performance Computing and Communications program, to accelerate progress in the advancement of computing and networking technologies and to support leading edge computational research in a range of science and engineering fields. The name of the program has evolved to the Networking and Information Technology Research and Development (NITRD) program. The statute established a set of mechanisms and procedures to provide for the interagency planning, coordination, and budgeting of the research and development activities carried out under the program.

For FY 2009, 13 federal agencies will contribute funding to the NITRD program and additional agencies that do not contribute funding participate in planning activities. The FY 2009 budget request for the NITRD program is $3.548 billion, an increase of $0.207 billion or approximately six percent, over the FY 2008 level of $3.341 billion. A summary of the major research components of the program and funding levels by major component and by agency is available at: *http://www.nitrd.gov/pubs/2009supplement/index.htm*

Assessment of NITRD by the President's Council of Advisors on Science and Technology (PCAST)

P.L. 102–194 provided for an external advisory committee for the NITRD program. A subsequent executive order created the President's Information Technology Advisory Committee (PITAC). The current Administration allowed that committee to expire and in its place assigned the advisory function for the NITRD program to PCAST. Last August PCAST completed an assessment of the NITRD program and issued a report, "Leadership Under Challenge: Information Technology R&D in a Competitive World" [*http://www.nitrd.gov/pcast/reports/PCAST-NIT-FINAL.pdf*].

The PCAST report includes several findings and recommendations related to the research content of the program, as well as suggestions for improving the program's planning, prioritization and coordination. The recommendations from the PCAST report include:

- Federal agencies should rebalance their NITRD funding portfolios by increasing support for important problems that require larger-scale, longer-term, multi-disciplinary R&D and increasing emphasis on innovative and therefore higher-risk but potentially higher-payoff explorations.
- As new funding becomes available for the NITRD program, disproportionately larger increases should go for:
  - research on NIT systems connected with the physical world (which are also called embedded, engineered, or cyber-physical systems);
  - software R&D;
  - a national strategy and implementation plan to assure the long-term preservation, stewardship, and widespread availability of data important to science and technology; and
  - networking R&D, including upgrading the Internet and R&D in mobile4networking technologies.
- The NITRD agencies should:
  - develop, maintain, and implement a strategic plan for the NITRD program;
  - conduct periodic assessments of the major components of the NITRD program and restructure the program when warranted;
  - develop, maintain, and implement public R&D plans or roadmaps for key technical areas that require long-term interagency coordination and engagement; and

  - develop a set of metrics and other indicators of progress for the NITRD program, including an estimate of investments in basic and applied research, and use them to assess NITRD program progress.

- The NITRD National Coordination Office should support the development, maintenance, and implementation of the NITRD strategic plan and R&D plans for key technical areas; and it should be more proactive in communicating with outside groups.

Cyber-Physical Systems

The top recommendation of the PCAST report for new research investments in the NITRD program is in the area of computer-driven systems connected with the physical world—also called embedded, engineered, or cyber-physical systems (CPS). CPS are connected to the physical world through sensors and actuators to perform crucial monitoring and control functions. Such systems would include the air-traffic-control system, the power-grid, water-supply systems, and industrial process control systems. On a more individual level, they are found in automobiles and home health care devices.

Examples of CPS are already in widespread use but growing demand for new capabilities and applications will require significant technical advances. Such systems can be difficult and costly to design, build, test, and maintain. They often involve the intricate integration of myriad networked software and hardware components, including multiple subsystems. In monitoring and controlling the functioning of complex, fast-acting physical systems (such as medical devices, weapons systems, manufacturing processes, and power-distribution facilities), they must operate reliably in real time under strict constraints on computing, memory, power, speed, weight, and cost. Moreover, most uses of cyber-physical systems are safety-critical: they must continue to function even when under attack or stress.

There is evidence that CPS will be an area of international economic competition. For example, the European Union's Advanced Research and Technology for Embedded Intelligence and Systems (ARTEMIS) program, funded by a public-private investment of 5.4 billion euros (over $7 billion in mid-2007 dollars) between 2007 and 2013, is pursuing R&D to achieve "world leadership in intelligent electronic systems" by 2016.

Recent Amendments to P.L. 102–194 [included in COMPETES Act]

In 1999, the PITAC released an assessment of the NITRD program ("Information Technology Research: Investing in Our Future") that found the research sponsored to be migrating too much toward support for near-term, mission focused objectives; that found a growing gap emerging between the power of high-performance computers available to support agency mission requirements versus support for the general academic research community; and that found the total federal information technology investment inadequate. In response to that report, the Committee developed legislation that passed the House in similar form in the 108th (H.R. 4218) and 109th (H.R. 28) Congresses, but failed to be picked up in the Senate. It was finally incorporated in the COMPETES Act (section 7024(a)) in this Congress.

The COMPETES Act amends the 1991 Act in several ways:

Program Planning. Specifies that the external advisory committee for the program, which must be re-constituted as a separate stand-alone committee, must carry out biennial reviews of the funding, content and management of the interagency R&D program and report its findings to Congress. Also, the annual report on the program prepared by the OSTP Director must now describe how the program has been modified in response to advisory Committee's recommendations.

High-End Computing. Requires OSTP to develop and maintain a roadmap for developing and deploying very high-performance computing (high-end) systems necessary to ensure that the U.S. research community has sustained access to the most capable computing systems.

Large Scale Applications. Clarifies that Grand Challenge problems supported under the interagency program are intended to involve multi-disciplinary teams of researchers working on science and engineering problems that demand the most capable high performance computing and networking resources. Consistent with this requirement, the language also specifies that provision for access to high performance computing systems includes technical support to users of these systems.

5. Witness Questions

Dr. Greer was asked to provide an overview of the current planning and coordination mechanisms of the NITRD program, along with any recommendations on how to improve their effectiveness; a description of any actions by the NITRD agencies that have been taken, or that are in the planning stages, in response to the recommendations of the PCAST report; a description of the role of the National Coordination Office in supporting the activities of the NITRD program; and his response to the findings and recommendations of the PCAST report related to the functioning of the NCO.

The other witnesses were asked to review and comment on the findings and recommendations contained in the PCAST report regarding both the administration and planning for the NITRD program and also the research priorities that the program should address. They were asked for their views on the merit of these recommendations and on what they see as the key steps to take that would strengthen the NITRD program, including any issues not addressed by the PCAST report.

Mr. Winter was particularly asked to provide his views on the PCAST recommendation related to the need for the NITRD program to place greater emphasis on research on cyber-physical systems.

Chairman GORDON. I want to welcome everyone to this morning's hearing to review the federal, interagency research initiative in networking and information technology, known as the NITRD program.

Information technology is a major driver of economic growth. It creates high-wage jobs, provides for rapid communication throughout the world, and provides the tools for acquiring knowledge and insight from information. Advances in computing and communications have a broad impact. For example, information technology helps to make the workplace more productive, to improve the quality of health care, and to make government more responsive and accessible to the needs of our citizens. In short, networking and information technology is an essential component of U.S. scientific, industrial, and military competitiveness.

Vigorous long-term research is essential to realize the potential benefits of information technology. Many of the technical advances that led to today's computers and the Internet resulted from federally sponsored research, in partnership with industry and universities.

The depth and strength of U.S. capabilities in information technology stem in part from the sustained research and development program carried out by the federal research agencies under a program codified by the *High-Performance Computing Act of 1991.* The Science and Technology Committee has a long history of encouragement and support for research on information technologies and played a prominent role in the development and passage of the 1991 Act.

The Act created a multi-agency R&D program to accelerate the development of information technology and to attack challenging computational science and engineering problems. Also, it put in place a formal process for planning and budgeting for the activities carried out under what is now known as the NITRD program.

The fiscal year 2008 budget for this interagency program is $3.3 billion. The agencies providing the largest portions of this funding are the Department of Defense, the National Science Foundation, the Department of Energy, and the National Institutes of Health.

I believe the NITRD program has been largely a success. It has made a substantial contribution to moving computation to an equal place along side theory and experiment for conducting research in science and engineering.

Moreover, it has developed the computing and networking infrastructure needed to support leading edge research and to drive the technology forward for a range of commercial applications that benefit society broadly.

The President's Council of Advisors on Science and Technology, the PCAST, recently carried out an assessment of the NITRD program. This assessment raises some significant issues about whether the NITRD program is allocating its resources in ways to achieve the maximum payoffs. PCAST makes a series of recommendations that identify research areas needing additional resources and suggests that the modes of research support provided by the program are less than optimum.

In particular, PCAST believes that the NITRD program should provide more of its funding for conducting high-risk/high-reward re-

search and support more large-scale, interdisciplinary research projects. It also recommends that the NITRD program institute a strategic planning process to strengthen priority setting under the program. I believe that PCAST raises issues that need to be seriously considered and then addressed, as appropriate, through the legislative adjustments to the NITRD authorizing statute. This hearing is the first step in a process, which the Committee will conduct next year.

To assist us in the development of legislation, this hearing provides the opportunity to receive the views of expert witnesses on the findings and recommendations of the PCAST assessment of the NITRD program. I am also interested in any comments or suggestions the witnesses may have on other aspects of the program that are not covered by the PCAST assessment but would lead to a more effective program.

I want to thank our witnesses for their attendance at this hearing and look forward to our discussions.

[The prepared statement of Chairman Gordon follows:]

PREPARED STATEMENT OF CHAIRMAN BART GORDON

I want to welcome everyone to this morning's hearing to review the federal, interagency research initiative in networking and information technology, known as the NITRD ["ny-ter D"] program.

Information technology is a major driver of economic growth. It creates high-wage jobs, provides for rapid communication throughout the world, and provides the tools for acquiring knowledge and insight from information.

Advances in computing and communications have broad impact. For example, information technology helps to make the workplace more productive, to improve the quality of health care, and to make government more responsive and accessible to the needs of our citizens.

In short, networking and information technology is an essential component of U.S. scientific, industrial, and military competitiveness.

Vigorous long-term research is essential for realizing the potential benefits of information technology. Many of the technical advances that led to today's computers and the Internet resulted from federally sponsored research, in partnership with industry and universities.

The depth and strength of U.S. capabilities in information technology stem in part from the sustained research and development program carried out by federal research agencies under a program codified by the *High-Performance Computing Act of 1991.* The Science and Technology Committee has a long history of encouragement and support for research on information technologies and played a prominent role in the development and passage of the 1991 Act.

The Act created a multi-agency R&D program to accelerate the development of information technology and to attack challenging computational science and engineering problems. Also, it put in place a formal process for planning and budgeting for the activities carried out under the NITRD program.

The Fiscal Year 2008 budget for this interagency program is $3.3 billion. The agencies providing the largest portions of this funding are the Department of Defense, the National Science Foundation, the Department of Energy, and the National Institutes of Health.

I believe the NITRD program has been largely a success. It has made a substantial contribution to moving computation to an equal place along side theory and experiment for conducting research in science and engineering.

Moreover, it has developed the computing and networking infrastructure needed to support leading edge research and to drive the technology forward for a range of commercial applications that benefit society broadly.

The technical advances that led to today's computing devices and networks, and the software that drive them, evolved from past research sponsored by industry and government, often in partnership, and conducted by industry, universities, and federal labs.

The President's Council of Advisors on Science and Technology—the PCAST—recently carried out an assessment of the NITRD program. This assessment raises

some significant issues about whether the NITRD program is allocating its resources in ways to achieve the maximum payoffs.

PCAST makes a series of recommendations that identify research areas needing additional resources and suggests that the modes of research support provided by the program are less than optimum.

In particular, PCAST believes that the NITRD program should provide more of its funding for conducting high-risk/high-reward research and support more large scale, interdisciplinary research projects. It also recommends that the NITRD program institute a strategic planning process to strengthen priority setting under the program.

I believe that PCAST raises issues that need to be seriously considered and then addressed, as appropriate, through legislative adjustments to the NITRD authorizing statute. This hearing is the first step in a process, which the Committee will conclude next year.

To assist us in the development of legislation, this hearing provides the opportunity to receive the views of expert witnesses on the findings and recommendations of the PCAST assessment of the NITRD program.

I am also interested in any comments or suggestions the witnesses may have on other aspects of the program that are not covered by the PCAST assessment, but which could lead to a more effective program.

I want to thank our witnesses for their attendance at this hearing and look forward to our discussion.

Chairman GORDON. And now I recognize my friend, Mr. Hall, for his opening statement.

Mr. HALL. Thank you, Chairman Gordon, for scheduling the oversight hearing of the NITRD Program. Of course, this program provides the primary mechanism by which the Federal Government coordinates this nation's more than $3 billion of unclassified networking information technology research and development investments, and you are absolutely correct in highlighting the PCAST report. To boil it down they simply said, "It is essential to U.S. economic prosperity, security, and quality of life." So given the ever-increasing amounts of networking and information technology that affect our everyday lives from power grid and water purification systems to automotive improvements and air traffic control equipment to home health care devices and educational software programs, it is important that we not only continue to support these R&D efforts but also make sure that this program is appropriately coordinating with our classified Cyber Security Initiatives as well. In fact, I believe that this is of vital importance to our homeland security and to our economy.

We have before us today an esteemed panel of NIT experts, and I look forward to hearing their views and how to make an already exemplary interagency program even better, and I yield back my time.

[The prepared statement of Mr. Hall follows:]

PREPARED STATEMENT OF REPRESENTATIVE RALPH M. HALL

Thank you Chairman Gordon for scheduling this oversight hearing on the NITRD program. This program provides the primary mechanism by which the Federal Government coordinates this nation's more than three billion dollars of unclassified networking and information technology (NIT) research and development (R&D) investments.

The United States is the global leader in NIT, and I agree with the authors of the PCAST Report on this issue when they say that our continued leadership "is essential to U.S. economic prosperity, security, and quality of life."

Given the ever increasing amounts of networking and information technology that affect our everyday lives from power grid and water purification systems to automotive improvements and air traffic control equipment to home health-care devices and educational software programs, it is important that we not only continue to support these R&D efforts but also make sure that this program is appropriately coordi-

nating with our classified cyber security initiatives as well. In fact, I believe that this is of vital importance to our homeland security and to our economy.

We have before us today an esteemed panel of NIT experts, and I look forward to hearing their views on how to make an already exemplary interagency program even better.

Chairman GORDON. Thank you, Mr. Hall. At this time we normally ask that Members who want to submit their opening statements, but since Mr. Sensenbrenner, because of his new status, we will allow him to make any statements that he would like to at this time.

Mr. SENSENBRENNER. Mr. Sensenbrenner is a man of few words unless they are really necessary. Not this morning. I thank the Chair.

Chairman GORDON. All right. If that is the case, then if Members would like to submit additional opening statements, they will be added to the record at this point.

[The prepared statement of Ms. Johnson follows:]

PREPARED STATEMENT OF REPRESENTATIVE EDDIE BERNICE JOHNSON

Good morning, Mr. Chairman and Ranking Member.

Today's hearing on oversight of the Networking and Information Technology Research and Development (NITRD) Program is important.

The Committee on Science and Technology is tasked with the important activity of seeing that our federal resources are allocated responsibly.

Investment in information technology is important to our nation, and it is important to Texas.

Texas Instruments, located in Dallas, has been a leader in information technology. Our state has been a welcoming place for high-tech development, as is evidenced by cities like Austin, Dallas and Houston gaining reputation as high-tech hubs.

The President's Council of Advisors on Science and Technology recently assessed the NITRD Program, and today's hearing will be important to determine whether the objectives of the program address the most important information technology R&D issues facing our nation.

We need to know if this program's research objectives are prioritized well, and whether currently allocated resources are appropriate to achieve these objectives.

It is the Committee's distinct honor to have witnesses representing the NITRD program, as well as the President's Council of Advisors on this issue, as well as academic and industry representatives who can offer unique perspectives.

Computer networking has become very sophisticated. Systems of computerized sensors perform crucial monitoring and control functions. Such systems include the air-traffic-control system, the power-grid, water-supply systems, and industrial process control systems. On a more individual level, they are found in automobiles and home health care devices.

Our nation must continue to innovate and stay at the leading edge of this kind of technology. Other nations are currently investing heavily in this activity and are gaining competitive ground.

Take, for example, the European Union's Advanced Research and Technology for Embedded Intelligence and Systems (ARTEMIS) program.

This effort is funded by a public-private investment of 5.4 billion euros (over $7 billion in mid-2007 dollars) between 2007 and 2013, is pursuing research to achieve "world leadership in intelligent electronic systems" by 2016.

President's Council of Advisors on Science and Technology have provided guidance on how our NITRD program should move forward.

Principal among their recommendations is the suggestion to rebalance agency funding portfolios to support more long-term projects, as well as research that is considered to be high-risk.

The Council also advised that greater proportions of funding should go toward research in networking information technology systems that are connected with the physical world; and for mobile networking technologies.

In addition, the Council urged agencies to implement a strategic plan for the NITRD program; and they should develop metrics to assess the progress of investments in research in these areas.

I want to thank the Council for their work to assess the NITRD program.

I hope that the recommendations, as well as this hearing, will help the Science Committee continue to be a good steward when it comes to allocation of funds for computer networking research.

[The prepared statement of Mr. Mitchell follows:]

PREPARED STATEMENT OF REPRESENTATIVE HARRY E. MITCHELL

Thank you, Mr. Chairman.

Today we will examine current status of the Networking and Information Technology Research and Development (NITRD) program.

In 1999, an assessment of the NITRD program by the President's Information Technology Advisory Committee (PITAC) concluded that the research sponsored by NITRD focused too much on near-term, mission focused objects.

In response, a provision in the *America COMPETES Act,* legislation that was drafted by this committee and now public law, aims to ensure that the NITRD supports large scale applications.

I look forward to hearing more today from our witnesses about what other legislative changes are necessary to the NITRD program.

I yield back.

Chairman GORDON. At this time I would like to introduce our witnesses, and we have a very distinguished group here. First, Dr. Chris Greer is the Director of NITRD National Coordination Office. Welcome. Dr. Daniel Reed is the Director of Scalable and Multicore Computing at Microsoft. Dr. Craig Stewart is Associate Dean of Research Technologies at Indiana University. He is representing the Coalition for Academic Scientific Computation. And finally, Dr. Don Winter is the Vice President of Engineering and Information Technology for the Phantom Works, Boeing Company.

Our witnesses should note we try to limit our spoken testimony to five minutes each which then Members will have an opportunity to question for five minutes. But this is an important topic. We have Members at a variety of other hearings today, and so we want to be sure we get all the information so please feel free to again, if you need a few more minutes to give us what you think is best, we want to hear from that.

At this point, let us start with Dr. Greer.

STATEMENT OF DR. CHRISTOPHER L. GREER, DIRECTOR, NATIONAL COORDINATION OFFICE FOR NETWORKING AND INFORMATION TECHNOLOGY RESEARCH AND DEVELOPMENT (NCO/NITRD)

Dr. GREER. Good morning. I am Chris Greer, and I am Director of the National Coordination Office for Networking and Information Technology Research and Development, the NITRD Program. I want to thank Chairman Gordon, Ranking Member Hall, and the Members of the Committee for the opportunity to come here today to discuss this important issue with you. I am also accompanied by a number of members seated behind me of the NCO NITRD staff, and it is an honor to sit here and represent the remarkable work of that group. And I commend this committee for initiating the *High-Performance Computing Act of 1991* and its subsequent amendments, with its remarkably far-sighted mandate for R&D coordination. The resulting federal program now in its 17th year has become a model for multi-agency cooperation. The program has grown substantially in size and scope since 1991. Today NITRD encompasses $3.5 billion in R&D across 13 member agencies as of the President's 2009 budget.

NITRD investments further our nation's goals for national defense and national security, health care, energy, education, economic competitiveness, environmental sustainability, and other national priorities.

My written testimony provides detailed responses to the questions the Committee asked me to address. In my remarks today, I want to highlight strategic planning. This is NITRD's main program-wide coordination activity, and Appendix 3 of that written testimony provides a detailed timeline for that strategic planning and road mapping process. But in fact, even if the PCAST, the President's Council Advisors on Science and Technology, hadn't recommended that NITRD develop a strategic plan, it would still be the right time in the program's history to consider where NITRD is going and how we can better manage that journey.

The networking and IT landscape is shifting rapidly, and major new national challenges are emerging. The program has recently been tasked, for example, with expanded coordination responsibilities under the federal plan for advanced networking R&D, and the Administration's comprehensive National Cyber Security Initiative. The PCAST assessment of NITRD with its provocative and important focus on rising global competition for networking and IT leadership sharpens our thinking about the role of strategic planning and shaping NITRD growth and change to meet national needs. The PCAST report's 17 recommendations, seven of which go to the issue of planning, provide a unique opportunity to make progress toward our goals. The NITRD Subcommittee last November approved development of a comprehensive strategic plan for NITRD and authorized my office to add a technical staff member dedicated to support of that activity.

The NITRD Subcommittee has agreed that the plan should be first vision driven with the theme of complexity and multiple dimensions. Second, focused on goals and capabilities that can only be achieved through interagency cooperation and coordination and the R&D capabilities and challenges required to achieve those goals. It should also be predictive of an effective organizational structure for the NITRD program.

As shown on the timeline in my written testimony, NITRD's strategic planning task group is working intensively on the plan now, including steps to solicit broad, private-sector input to the planning process.

A request for input has just now been published in the Federal Register and widely disseminated to academia, to industry, and to professional organizations. A national workshop planned for November 2008 will provide a second opportunity for public input, and the final draft will be posted for public comment in early 2009.

That timeline also shows that PCAST recommendations on assessing the alignment of the NITRD research areas initiating an NCO plan to support the overall planning process, and preparing a fast-track education study are also being addressed.

Other PCAST recommendations will be integrated into the NITRD planning enterprise as the comprehensive strategic plan takes shape and provides the larger context. Upon completion of this strategic plan, we anticipate providing a point-by-point re-

sponse to the PCAST recommendations informed and supported by that plan.

We agree with PCAST that leadership in networking and information technology is essential to U.S. economic prosperity, security, and quality of life. The federal investments that we make in research and development in this area are the keys to a future of promise for our nation and for its citizens.

I look forward to working with the Congress to fulfill that promise. Thank you.

[The prepared statement of Dr. Greer follows:]

PREPARED STATEMENT OF CHRISTOPHER L. GREER

Good morning. My name is Chris Greer and I am Director of the National Coordination Office (NCO) for Networking and Information Technology Research and Development (NITRD). With my colleague, Dr. Jeannette Wing of the National Science Foundation (NSF), I co-chair the NITRD Subcommittee of the National Science and Technology Council's (NSTC) Committee on Technology. I want to thank Chairman Gordon, Ranking Member Hall, and the Members of the Committee for the opportunity to come before you today to discuss the Federal Government's multi-agency NITRD effort.

The NITRD Program—now in its 17th year—represents the Federal Government's portfolio of unclassified investments in fundamental, long-term research and development (R&D) in advanced networking and information technology (IT), including high-end computing, large-scale networking, cyber security and information assurance, human-computer interaction, information management, high-confidence software and systems, software design, and socioeconomic, education and workforce implications of IT. NITRD research is performed in universities, federal research centers and laboratories, federally funded R&D centers, private companies, and non-profit organizations across the country. Agencies participating in the NITRD program—including 13 member agencies and a number of other participating agencies and offices—support vital investments in R&D and research infrastructure to further our nation's goals for national defense and national security, health care, energy, education, economic competitiveness, environmental sustainability, and other national priorities. Through the NITRD program, federal agencies work together to ensure that the impact of their efforts is greater than the sum of their individual investments. This is accomplished through interaction across the government, academic, commercial, and international sectors using cooperation, coordination, information sharing, and joint planning to identify critical needs, avoid duplication of effort, maximize resource sharing, and partner in investments to pursue higher-level goals.

Mandate for coordination

Seventeen years ago, when Congress passed the bipartisan *High-Performance Computing (HPC) Act of 1991* (Public Law 102–194), the Act's mandate for interagency coordination of federal networking and IT R&D was remarkably farsighted. The Act established a powerful, resilient framework for federal networking and IT R&D activities. That framework combined ambitious research goals with specific requirements for interagency cooperation, collaboration, and partnerships with industry and academia. The validation of the HPC Act's core vision can be found in the success and vitality of today's NITRD Program, which has become a model for coordination across federal agencies.

The HPC Act was amended by the *Next Generation Internet Research Act of 1998* (Public Law 105–305) and the *America COMPETES Act of 2007* (Public Law 110–69). These Acts extended the scope of responsibilities for interagency coordination to include human-centered systems; flexible, extensible, inter-operable, and accessible network technologies and implementations; education, training, and human resources; and other areas. As a result, the NITRD Program now provides for cooperation and coordination across a broad landscape, allowing it to tackle the inherently multi-disciplinary, multi-technology, and multi-sector challenges of today's networking and IT research horizons.

The Office of Science and Technology Policy (OSTP), with the support of the Office of Management and Budget (OMB) and the participating NITRD agencies, has taken a vigorous approach to implementing the enabling NITRD legislation. The NCO Director is a member of the OSTP technical staff group with direct access to

and active support by OSTP and OMB staff and leadership. In addition to their financial contributions, the participating agencies provide the time of some of their most capable experts and senior managers to pursue NITRD goals. The success of NITRD is due in large measure to the dedication and commitment of those who implement the program.

Program history in brief

In its first annual report to the Congress, the then-High Performance Computing and Communications (HPCC) Program reported an estimated 1991 multi-agency budget of $489.4 million and a proposed 1992 budget of $638.3 million. Eight federal agencies were represented in that budget: Defense Advanced Research Projects Agency (DARPA), Department of Energy (DOE), Environmental Protection Agency (EPA), National Aeronautics and Space Administration (NASA), National Institutes of Health (NIH), National Institute of Standards and Technology (NIST), National Oceanic and Atmospheric Administration (NOAA), and National Science Foundation (NSF). The HPCC program had four major research areas called Program Component Areas (PCAs): High Performance Computing Systems (HPCS); Advanced Software Technology and Algorithms (ASTA); National Research and Education Network (NREN); and Basic Research and Human Resources (BRHR).

Since 1991, the Federal IT R&D program has evolved continuously, addressing the continuing, dramatic expansion in computing and networking technologies, applications, and societal needs by adjusting the research focus and adding new, emerging areas of interest. This includes disaggregating investments in high-end computing infrastructure and applications from those in high-end computing (HEC) systems and system software research, and adding software design and productivity, high-confidence software and systems, and societal and workforce implications of IT.

Today, the NITRD Program, which is successor to the original HPCC Program, encompasses $3.5 billion (2009 Budget Request) in R&D funding and comprises 13 member agencies—the original eight agencies plus Agency for Healthcare Research and Quality (AHRQ), National Archives and Records Administration (NARA), Department of Energy/National Nuclear Security Administration (DOE/NNSA), National Security Agency (NSA), and Office of the Secretary of Defense and Department of Defense Service research organizations (OSD and DOD Service research organizations). About a dozen other agencies that are not formal NITRD members also participate in the eight Program Component Areas (PCAs) and other NITRD activities. (See Appendix 1 on page 14 for a list of the current NITRD agencies and PCAs and a NITRD organizational chart.)

Response to the Committee Request

The invitation to testify from this House Committee included a request to address three topic areas. Responses are provided in the numbered sections that follow.

Request #1: Current planning and coordination overview

The NITRD Program uses five general mechanisms to pursue its mission:

(1) Monthly meetings of the seven Federal Interagency Working Groups (IWGs) and Coordinating Groups (CGs) chartered under the auspices of the NSTC
(2) Workshops, most including private-sector as well as federal participants
(3) Formal reports, including the annual NITRD Supplement to the President's Budget and strategic planning documents
(4) Support for external studies and assessments
(5) Outreach to the federal and private sectors

I'll illustrate how these are used with examples for each mechanism.

In each NITRD Program Component Area (PCA), agencies work together in a CG or IWG that meets monthly to identify research needs, plan programs, share best practices, and review progress. These regular meetings allow groups to explore complex research and development challenges. As an example, the High Confidence Software and Systems (HCSS) CG is playing a leadership role in engaging researchers and industry in assessing the national research needs in the complex life- and safety-critical technologies called cyber-physical systems[1] (defined here as IT embedded in and critical to the function of a physical system; aircraft avionics are an example). This analysis is being informed by a workshop series engaging the aca-

[1] In its 2007 assessment of the NITRD Program, the President's Council of Advisors on Science and Technology (PCAST) termed cyber-physical systems "a national priority for Federal R&D."

demic, commercial, and government sectors. Recent workshops in this series covered medical device software and systems, with participation by researchers, clinicians, hospital administrators, and industry representatives; another focused on automotive safety, engaging automobile designers, safety experts, and engineers and academic researchers. The next in the series, planned for Fall 2008, will focus on "High Confidence Cyber-Physical Transportation Systems: A look at the Commercial Aero, Auto, and Rail Sectors, and Military Ground and Aerial Unmanned Autonomous Vehicles (UAVs)."

During the 20-month period from October 2006 to May 2008, the NITRD Program planned and held a total of 27 workshops—an average of 1.5 workshops per month. Topics include composable cyber systems, supervisory control and data acquisition (SCADA) systems for industrial process/system control, and an upcoming event on national and international networking research challenges. An ongoing series, the Collaborative Expedition Workshops, covers wide-ranging topics such as virtual work settings, evaluation of emerging technology and technology development programs, and scalable data management.

Formal reports produced during this same 20-month period include the 2007 and 2008 NITRD Supplement to the President's Budget and the following strategic planning documents produced by ad hoc interagency task groups of NITRD member agencies and others:

Federal Plan for Advanced Networking Research and Development

On January 30, 2007, OSTP Director Jack Marburger established an Interagency Task Force on Advanced Networking and charged it with developing a strategic vision and long-range plan for federal networking R&D; he requested that the initial draft of the plan be completed in three months, by May 2007, to provide timely input for the FY 2009 budget process. Through intensive efforts, the 40-member task force of NITRD and other agency representatives produced a draft on schedule, including a detailed analysis of networking research challenges that has been extremely well received. The Task Force continued to refine the draft over the next 12 months; the final *Federal Plan for Advanced Networking Research and Development* is now being printed and will be sent to all Members of Congress shortly. The preprint version of the Plan is available on the NITRD Web site at: *http://www.nitrd.gov/ITFAN-preprint-061108.pdf*

Plan for Coordination of Federal R&D and Plan for the Leap-Ahead Program of Research and Development

In February 2008, OSTP called for an Interagency Task Force from NITRD agencies and others to develop two research-related planning documents on a fast-track basis under the Comprehensive National Cybersecurity Initiative (CNCI), established by National Security Presidential Directive 54/Homeland Security Presidential Directive 23 in January 2008. To expedite quick turnaround on this tasking, the 21 task force members divided into two groups. One developed the plan for overall coordination of the federal cyber R&D portfolio; the other crafted the "Leap-Ahead" plan for accelerating high-risk, high-return research to help maintain our technological edge in cyberspace. These plans now provide the basis for the recent launch of the CNCI R&D planning activities.

Under the CNCI plans, the Cyber Security and Information Assurance Interagency Working Group (CSIA IWG) chartered by the NSTC in 2006—augmented by a new Senior Steering Group—is tasked with two new assignments: leading the CNCI R&D coordination activity including improving coordination between the unclassified and classified Federal R&D sectors, and coordinating the "Leap-Ahead" initiative. The CSIA IWG's 2006 *Federal Plan for Cyber Security and Information Assurance Research and Development* provides a detailed technical baseline for setting federal cyber R&D priorities under CNCI.

The NITRD Program supports external studies and reviews to expand its perspectives and take advantage of expertise from a diversity of sources. A study by the National Academies is currently underway to develop a better understanding of the potential scientific and technological impact of high-end capability computing in science and engineering. Public release of the final report is expected in September 2008. The Program recently provided briefings and written inputs to the Networking and Information Technology Subcommittee of the President's Council of Advisors on Science and Technology (PCAST) for use in its assessment of the NITRD Program. Looking ahead, the Program developed a statement of work for the first of the fast-track studies on NIT post-secondary education called for by the PCAST assessment of NITRD.

The NITRD Program uses a variety of mechanisms to reach out to researchers, private-sector developers, resource providers, and end-users. Examples include two groups under the Large Scale Networking CG: the Joint Engineering Team (JET) and Middleware and Grid Infrastructure Coordination (MAGIC) group, which have academic and industry members; the Federal Agency Administration of Science and Technology Education and Research (FASTER) Community of Practice (CoP), which seeks exchanges of information with the private sector and new technologies to streamline the management of federal research; and the multi-sector NITRD research workshops held in all the PCAs.

A number of efforts are underway to improve the effectiveness of NITRD planning and coordination. These include revamping the NITRD web site (both public and federal-only resources), providing improved web-based services to support remote participation and digital content sharing, and outreach visits by NCO technical staff to academic and commercial organizations as a required component of regular conference travel.

The high sustained level of collaborative engagement reflected in the diverse NITRD activities of the last two years is, in my judgment, a key measure of the effectiveness of the NITRD coordination model—it remains resilient amid the Program's increasing activities and expanding responsibilities. Another measure is the productive synergy gained through joint funding, partnerships with private-sector entities, and sometimes a combination of the two. For example:

Collaboration

Benchmarks for Federal HEC systems: The HEC agencies are collaborating to develop an interagency suite of HEC benchmarks that can accurately represent the demands of federal advanced computing applications.

IPv6 debugging: DOD, DOE/SC, and NASA are collaborating, in cooperation with the university networking consortium Internet2, in a project that is conducting end-to-end debugging, performance measurement, and toolset enhancement of Internet Protocol version 6 (IPv6) over DOD's Defense Research and Education Network (DREN), DOE/SC's Energy Sciences network (ESnet), and Internet2Net.

Environmental databases and data distribution: Through the Earth System Modeling Framework activity and related efforts, NITRD agencies (DOD, EPA, NASA, NOAA, NSF) continue their long-range cooperative work to expand the interoperability and usability of diverse models and large-scale data sets for weather, climate, and environmental research.

Joint funding/Partnerships

High-Productivity Computing Systems (HPCS) Phase III: This DARPA effort, supported also by DOE/SC and NSA and with collaborative participation by other HEC agencies, involves design, fabrication, integration, and demonstration of full-scale prototypes by 2010 for a new generation of petascale, economically viable computing systems.

HEC–University Research Activity (HEC–URA): In 2004, HEC R&D agencies (DARPA, DOE/NNSA, DOE/SC, NASA, NSA, and NSF) initiated this program of high-risk R&D in technically challenging areas including HEC software tools and compilers; file systems, I/O, and storage design for high throughput; and new parallel programming models for thousands of processors. DARPA, DOE/SC, and NSF have contributed funding, and they and other HEC agencies participate in reviews and HEC–URA workshops.

DETERlab: DHS and NSF, with university and industry partners, are supporting the cyber-DEfense Technology Experimental Research laboratory testbed, a general-purpose experimental infrastructure that enables research and development on next-generation cyber security technologies.

Open Science Grid (OSG): NSF and DOE/SC are jointly supporting this growing consortium of about 100 researchers and software, service, and resource providers from universities, national laboratories, and computing centers across the U.S. OSG brings together distributed computing and storage resources from campuses and research communities in a common, shared grid infrastructure over research networks via a common set of middleware.

Trustworthy Cyber Infrastructure for the Power Grid (TCIP): In this effort co-funded by NSF, DOE (OE), and DHS, researchers from the University of Illinois at Urbana-Champaign, Dartmouth College, Cornell University, and Washington State University are seeking to better secure operations of the Nation's power grid

by improving the engineering of its underlying IT infrastructure, making it more secure, reliable, and safe.

Cluster Exploratory (CluE) program: NSF has formed a partnership with Google and IBM that will enable academic researchers to explore data-intensive computing applications in science and engineering using a 1,600-processor server farm set up and supported by the two companies.

Committee Request #2: PCAST assessment of the NITRD Program

Periodic assessments of the multi-agency networking and IT R&D program by a Presidential advisory committee are mandated by the HPC Act, as amended by the *Next Generation Internet Research Act of 1998* and most recently by the *America COMPETES Act of 2007.* Executive Order 13385, signed September 29, 2005, assigned the assessment responsibility to PCAST, which in 2006 established a Networking and Information Technology (NIT) Subcommittee to lead the process. The results of PCAST's assessment are presented in the August 2007 report *Leadership Under Challenge: Information Technology R&D in a Competitive World.*

Over all, the PCAST concluded that while the NITRD program, with NCO support, has in the past "been effective at meeting agency and national needs," for the future "changes are needed in order for the United States to ensure its continued leadership." This conclusion recognizes the advent of an era of global NIT competitiveness in which "other countries and regions have also recognized the value of NIT leadership and are mounting challenges." The changes recommended by PCAST are in the areas of education and workforce development, portfolio balance, new emphasis areas, and strategic planning. The PCAST conclusions and recommendations sharpen our focus on the central role of strategic planning in shaping NITRD growth and change; and even in the most technically difficult R&D areas such as complex software, the PCAST recommendations provide an opportunity to make progress toward our goals.

The PCAST makes 17 recommendations in its report. (The recommendations are listed numerically, in sequence by chapter, in Appendix 2. Recommendations are noted parenthetically by number in this testimony.) These recommendations can be categorized as follows:

(1) Seven focus on improved planning processes (#9, 11–13, 16, 18, 20)
(2) Four address issues of portfolio balance and emphasis areas (#2a, 6, 8, 14)
(3) Two suggest studies or consultations (#1, 10)
(4) Two focus on assessment (#17, 19)
(5) Two are addressed to the Director of OSTP (#7, 15)
(6) Three call for efforts to ease the visa process for international students, graduates, and visiting experts (#2b, 2c, 2d)

The final two categories fall outside the purview of NITRD and this testimony, and will not be addressed further. I would like to address the first four categories with a few comments and observations on each.

PCAST Category 1: Planning recommendations

The PCAST assessment comes at a developmental turning point for NITRD. In light of the maturation and increase in responsibilities I have described, it is clearly the right time in NITRD history to consider where we are going and how we can better manage the journey. For this reason, and in light of the PCAST assessment, the NITRD Subcommittee has initiated the development of a comprehensive strategic plan. The key features of this plan are that it is:

- Vision-driven with a theme of complexity in multiple dimensions
- Focused on goals and capabilities that can only be achieved through interagency cooperation and coordination, and the R&D capabilities and challenges required to achieve those goals
- Predictive of an effective organizational structure for the NITRD Program

With the development of a comprehensive strategic plan, we anticipate a point-by-point response to the PCAST recommendations informed and supported by the plan.

Process for developing NITRD Strategic Plan

At its November 2007 meeting, the NITRD Subcommittee approved an initiative to prepare a new Strategic Plan for NITRD as the critical initial task for entering a new phase of development. A detailed timeline for the strategic planning process,

with milestones, is provided in Appendix 3 (note that the timeline also lists the PCAST recommendations relevant to the various steps in the process). This timeline covers the period FY 2008–09 and has five major features:

(1) The plan development process has three subphases—initial content development March through September 2008; text drafting and revision September 2008 through March 2009; and concurrence review with a target for release in June 2009.

(2) The process provides multiple opportunities and mechanisms for public input including a Request for Input (RFI) for initial comments, a workshop to engage all sectors, and public comments on a full draft plan.

(3) The PCAST recommendations are fully integrated into and help guide the strategic planning process.

(4) The development of PCA strategic plans and roadmaps overlaps with and is informed by the culmination of the NITRD strategic planning process.

(5) The strategic planning process is viewed as ongoing with regular opportunities in the future for evolving and revising the plan as goals are achieved and the networking and IT landscape changes.

Agency representatives kicked off the strategic planning process with a two-day off-site meeting in March 2008. First principles agreed upon at that meeting were that the NITRD Strategic Plan should align with the strategic plans of the member agencies, and that the Plan should focus on long-term capabilities that require the research contributions of multiple agencies to achieve. An 18-member strategic planning team of agency representatives is now meeting weekly and is currently focused on the task of initial content development. A Request for Input (RFI) appeared in the *Federal Register* July 24 and notification has been sent to stakeholder organizations across the country as well as to the NCO's outreach list of approximately 1,700 contacts. The two-page RFI (see Appendix 3) asks all interested parties—individuals, groups, organizations, and representatives of companies and industries—to provide a two-page statement envisioning the future of networking and IT and the future role of NITRD.

In developing its strategic plan, NITRD is also coordinating closely with the NSTC Committee on Science's Interagency Working Group on Digital Data (IWGDD). The IWGDD is charged with developing and providing for the implementation of a plan to cultivate a framework for reliable preservation and effective access to digital scientific data. Along with Cita Furlani of NIST and Charles Romine of OSTP, I serve as co-chair of the IWGDD.

PCAST Category 2: Recommendations on portfolio balance and emphasis areas

This category of PCAST recommendations recognizes and supports the current NITRD portfolio while suggesting increases in:

(1) larger-scale, longer-term, multi-disciplinary, and high-risk/high-payoff research; and

(2) support for NIT systems connected with the physical world, software, digital data, and networking, while continuing support for high-end computing, cyber security and information assurance, human-computer interaction, and NIT and the social sciences.

As PCAST recognizes, the NITRD Program fields a number of efforts in this first item today, including R&D in petascale architectures, software, and applications; all-optical network technologies; quantum information technologies; and next-generation wireless and sensor capabilities. At the same time, a key goal of NITRD's current strategic planning activity is to enable us to identify new opportunities for long-term, high-risk research investments. The plan's specific emphasis on goals and capabilities that can only be achieved by agencies working together is intended to enable agencies to share funding for larger and longer-term projects and to share the risk in projects whose payoffs are broad enough to interest multiple agencies. Furthermore, the Program's ability to move nimbly to seize such new opportunities is contingent in part on the alignment of the PCAs in which agencies report their NITRD research dollars. For that reason, one focus of our strategic planning activities is an unfettered examination of the PCAs to assess whether, and what type of, realignment of NITRD research areas might be desirable to promote new strategic directions. (This kind of Subcommittee assessment is also called for by the PCAST in a separate recommendation.)

High payoffs can also come from good ideas that are not necessarily high-risk. Two such examples are the opening up of computing cycles on federal leadership-class systems to the broader national research community and the investment by NSF in Track 2 HEC clusters. The NSF investment resulted in a dramatic increase in computational resources available over the Teragrid. The open solicitations for leading-edge computational research proposals by DOE/SC (under the Innovative and Novel Computational Impact on Theory and Experiment [INCITE] program) and NASA (under the former National Leadership Computing System [NCLS] program) have greatly broadened access for the national research community to the world's most powerful supercomputers. The 2008 INCITE competition resulted in awards of computing cycles on leadership-class federal systems to eight major U.S. corporations, 17 universities, and 20 smaller federal agencies and labs as well as international research institutions—for a total of more than a quarter of a billion compute hours.

The topic areas listed in the second item above (focused on cyber-physical systems) are emerging as crucial in the discussions of the NITRD strategic planning group. We concur with PCAST in its assessment of the importance of these topics and expect them to be central in the final strategic plan.

Although the PCAST report states that "over all, technology transfer has worked well in networking and IT," the NITRD Program has several new opportunities to address the report's recommendation that NITRD do more to exploit existing tech transfer mechanisms. Already existing NITRD mechanisms that bring researchers and their results together with private-sector developers and end-users include: the above mentioned JET and MAGIC groups; the Federal Agency Administration of Science and Technology Education and Research (FASTER) community of practice group, which seeks exchanges of information with the private sector and new technologies to streamline the management of federal research; and the multi-sector NITRD research workshops held in all the PCAs.

The new opportunities are presented by the two CNCI plans and the advanced networking plan. Each of these plans places substantial emphasis on developing new models for expanding substantive interactions with the private sector, such as cooperation on testbeds and increased meetings with industry organizations, and on expediting the movement of research results into prototyping and commercial implementation. The increasing pace of technological change is recognized in the NITRD community as a challenge in advancing research innovations, so there is eagerness now to explore ways to improve NITRD's outreach to private developers and industry.

The new CNCI activities also bear on the PCAST recommendation to increase the emphasis on long-term research and infrastructure in cyber security and information assurance. The NITRD Subcommittee has approved the addition of one FTE to the NCO staff to support the expanded responsibilities of the CSIA IWG and its new Senior Steering Group (SSG) for coordinating cyber R&D and the Leap-Ahead research initiative. Infrastructure for cyber security R&D is called for by both the CNCI planning documents and the CSIA IWG Federal Plan.

PCAST Category 3: Recommendations for consultations and studies

The dynamic and global networking and IT landscape will require a partnership across the government, academic, and commercial sectors if we are to maintain our nation's leadership role. This will require the Federal Government to act as both leader to and partner with the other sectors. The NITRD agencies can lead by making effective R&D investments, including those in larger, longer-term, multi-disciplinary, and high-risk/high-payoff efforts, and by setting examples, demonstrating feasibility, and developing initial implementation capabilities through their own NIT activities, such as achieving IPv6 capability. The NITRD agencies can be partners by being transparent and interactive in their R&D planning activities, exchanging information about emerging innovations and understanding the needs, opportunities, and capabilities in the other sectors.

This dual leadership/partnership role requires ongoing mechanisms for dialogue and interaction between the NITRD program and other sectors. As I mentioned earlier, the JET and MAGIC teams include academic and commercial-sector participation. This model could profitably be extended into other PCAs and focus areas. The NITRD workshops are designed to draw participation across sectors and to bring together groups with complementary interests and capabilities that do not have a history of interaction. This mechanism will continue to see extensive use. The PCAST assessment and its influence on NITRD activities demonstrates the value of high-level external review of the Program as an additional means for input. The *America COMPETES Act* calls for an ongoing, external review process.

The partnership role also includes making good use of the expertise and perspectives available in the other sectors. External studies commissioned by NITRD are one means for achieving this. For example, the PCAST assessment identifies as a priority area ensuring an adequate supply of well-educated NIT professionals, a strategic goal that we share. To inform the development of our strategic plan, the NITRD agencies have launched an initial fast-track study of networking and IT education. A Statement of Work developed by a multi-agency task group was approved at the March off-site meeting of the NITRD Subcommittee. We are also in the process of assessing the current NITRD educational activities including graduate fellowships to compare these against needs and against priorities of our strategic plan. Our initial plan includes a full-day workshop to discuss current programs across the federal agencies. Thus, the strategic planning process itself is an example of the use of multiple consultation and input mechanisms to inform planning.

Additional examples of external inputs are in the areas of software development and advanced networking. The recent National Academies study *Software for Dependable Systems: Sufficient Evidence?* has been complemented by the ongoing workshop series supported by the HCSS group that has drawn input from academia, industry, user groups, and government on certifiably dependable software systems for critical applications. The Federal Plan for Advanced Networking Research and Development was informed by a series of eight workshops, RFIs, working groups, and external reports.

PCAST Category 4: Recommendations on assessment

The PCAST assessment included recommendations for periodic assessment of the NITRD PCA structure and the development of metrics and indicators to assess progress. As I stated earlier, an explicit goal in the strategic planning process is to evaluate the current PCA structure against our new strategic plan and to make changes as appropriate. We envision the strategic planning process and any associated PCA realignments as an ongoing process, to be revisited on a regular basis as the networking and IT landscape evolves and as strategic goals are achieved.

There are currently two types of metrics or indicators against which we intend to assess progress. Stage One indicators include successful completion of the Strategic Plan and the PCA strategic plans and roadmaps—including measures of progress—called for in the PCAST report. The timeline in Appendix 3 provides a series of specific milestones and events, which are examples of Stage One indicators. Stage Two indicators—measures of how well the Program is carrying out its Strategic Plan, how effectively the PCAs are pursuing their strategic plans and roadmaps, and the impact of these efforts—are being developed as part of the strategic planning process. These Stage Two indicators will be an important part of our implementation plan.

Committee Request #3: Role and functions of the National Coordination Office for NITRD (NCO/NITRD)

The NCO/NITRD is identified in the NSTC Committee on Technology charter for the NITRD Subcommittee. The Office provides technical, planning, budgetary, and logistical support for all the activities of the NITRD Program, under the operative framework of relevant laws, charters, and Executive Branch directives. The Office also serves as the central point of contact for inquiries and requests for information about the Program and maintains the Program's Web site and documents, including current and archival documentation of NITRD subcommittee, IWG, and CG activities. The Director and Associate Director are federal employees and serve as senior management. The staff of 13 contractors and one federal employee on detail includes a contract manager and an office operations manager; five Technical Coordinators who support 11 IWGs, CGs, and technical groups; one writer/editor; three administrative support staff; a web master and an IT systems manager; and a temporary full-time coordinator for the NITRD strategic planning process. The five Technical Coordinators are Ph.D.-level positions that provide expert knowledge of the R&D challenges in the NITRD fields.

Regular NCO activities include logistical preparations and staff support for all meetings of NITRD entities, including those of the Presidential advisory group on IT, and most NITRD-affiliated workshops; drafting, editing, and publishing support for publications (annual budget supplement, R&D plans, workshop reports, studies, and reviews) of the NITRD Program and those of the Presidential advisory group; and preparation of special budgetary and technical documents requested by the NITRD Subcommittee. The NCO Director maintains close communications with OSTP, OMB, the NITRD agencies, and this Committee, and represents the Program in presentations to organizations nationally.

The PCAST assessment includes three recommendations that explicitly reference the NCO. Two focus on NCO support for the Subcommittee in commissioning studies on networking and IT education and in developing metrics and progress indicators for assessment. These support efforts are underway, as described above.

The third recommendation is that NCO, with Subcommittee guidance, should develop and implement a plan for supporting the NITRD Program in developing strategic plans and roadmaps. Such a plan has been developed for the initial stages of this new NITRD activity and is being implemented. Under this initial plan, the NCO has committed significant resources to the process, including the hiring of a temporary coordinator for strategic planning. The Office has committed significant technical writing time in preparing text and has charged the Technical Coordinators with serving as liaisons between the Strategic Planning Group and the IWGs and CGs. The Office is supporting the weekly meetings of the Strategic Planning Group and providing logistical support for its outreach activities. Thus, the NCO is fully committed to supporting a successful NITRD strategic planning and roadmapping process.

In conclusion

The enabling NITRD legislation and its vigorous implementation by OSTP, OMB, and the NITRD agencies have created a robust, responsive, and resilient framework for effective cooperation and coordination in federal networking and IT R&D planning and execution. The NITRD Program has matured and now encompasses a spectrum of NIT areas that allow it to take on the complex, multi-disciplinary, multi-sector challenges characteristic of today's networking and IT landscape.

With this maturation comes the opportunity and responsibility for comprehensive strategic planning to ensure best use of this important resource for coordination. The NITRD Program is now deep into the process of a vigorous strategic planning and roadmapping effort. We are confident that this process and its attendant elements will fully address the valuable recommendations contained in the PCAST assessment.

A measure of the strength of the NITRD Program and the supporting National Coordination Office is the ability to simultaneously support a vigorous strategic planning process, the development of coordination and leap-ahead R&D activities under the Comprehensive National Cybersecurity Initiative, manage two external studies, facilitate a robust workshop series, and conduct the regular planning, coordinating, and reporting activities of the 11 IWGs, CGs, and teams. This is only accomplished because of the competence, dedication, and commitment of all of the members of the NITRD/NCO community.

As the PCAST concludes, leadership in networking and information technology is essential to U.S. economic prosperity, security, and quality of life. The federal investments we make in research and development in this area are the keys to a future of promise for our nation and its citizens. I look forward to working with Congress to fulfill that promise.

Thank you.

Appendix 1: NITRD Agencies and Program Component Areas

Member agencies

AHRQ – Agency for Healthcare Research and Quality
DARPA – Defense Advanced Research Projects Agency
DOE/NNSA – Department of Energy/National Nuclear Security Administration
DOE/SC – Department of Energy/Office of Science
EPA – Environmental Protection Agency
NARA – National Archives and Records Administration
NASA – National Aeronautics and Space Administration
NIH – National Institutes of Health
NIST – National Institute of Standards and Technology
NOAA – National Oceanic and Atmospheric Administration
NSA – National Security Agency
NSF – National Science Foundation
OSD and Service research organizations (Office of the Secretary of Defense and DoD Air Force, Army, and Navy research organizations)

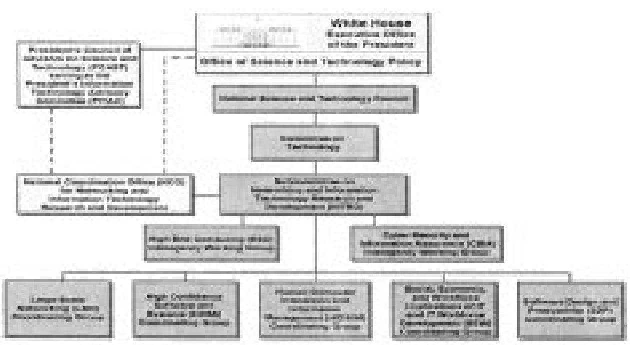
Participating agencies

CIA – Central Intelligence Agency
DHS – Department of Homeland Security
DNI – Office of the Director of National Intelligence
DOE (OE) – Department of Energy Office of Electricity Delivery and Energy Reliability
DOJ – Department of Justice
DOT – Department of Transportation
FAA – Federal Aviation Administration
FBI – Federal Bureau of Investigation
FDA – Food and Drug Administration
GSA – General Services Administration
IARPA – Infrastructure Advanced Research Projects Agency
State – Department of State
Treasury – Department of the Treasury
TSWG – Technical Support Working Group
USGS – U.S. Geological Survey

Program Component Areas, Interagency Working Groups/Coordinating Groups/Teams

High End Computing Infrastructure and Applications (HEC I&A) – HEC IWG
High End Computing Research and Development (HEC R&D) – HEC IWG
Cyber Security and Information Assurance (CSIA) – CSIA IWG
Human-Computer Interaction and Information Management (HCI&IM) – HCI&IM CG
Large Scale Networking (LSN) – LSN CG
LSN Teams:
Joint Engineering Team (JET)
Middleware and Grid Infrastructure Coordination (MAGIC)
High Confidence Software and Systems (HCSS) – HCSS CG
Social, Economic, and Workforce Implications of IT and IT Workforce Development (SEW) – SEW CG
Software Design and Productivity (SDP) – SDP CG

NITRD Program Structure



Appendix 2: PCAST Recommendations (numbered and by chapter)
(from *Leadership Under Challenge: Information Technology R&D in a Competitive World*)

Chapter 2: Networking and Information Technology Education and Training

Recommendation #1 (page 23)
To provide a solid basis for subsequent action, the NITRD Subcommittee should charge the NITRD National Coordination Office to commission one or more fast-track studies on the current state of and future requirements for networking and information technology undergraduate and graduate education.

Recommendation #2 (page 23)
To help meet national needs for personnel with advanced degrees in networking and information technology fields, the Federal government should:

- **#2a** Increase the number of multiyear fellowships for graduate study by American citizens in NIT fields each year, with the target number and fields of such fellowships informed by needs identified in sources such as the NIT education study
- **#2b** Streamline the process for obtaining visas for non-U.S. students admitted to accredited graduate degree programs in NIT subjects
- **#2c** Make it routine for foreign nationals who have obtained advanced degrees in NIT subjects at accredited U.S. universities to be permitted to work and gain citizenship in the United States by easing the visa and Green Card processes for them
- **#2d** Simplify the visa process for international NIT R&D experts who visit the United States on a regular or a frequent basis for professional purposes

Chapter 3: Profile of Federal Networking and Information Technology Research and Development

Recommendation #3 (page 26)
Federal agencies should rebalance their networking and information technology R&D funding portfolios by increasing: (1) support for important networking and information technology problems that require larger-scale, longer-term, multidisciplinary R&D and using existing or new mechanisms to address those problems and (2) emphasis on innovative and therefore higher-risk but potentially higher-payoff explorations.

Recommendation #4 (page 27)
The Director of the Office of Science and Technology Policy should call on senior officials from Federal agencies with large academic networking and information technology R&D budgets to meet with senior officials from the Nation's major research universities to address how better to conduct large-scale, long-term, multidisciplinary academic research in the development and application of networking and information technology important to the Nation.

Recommendation #5 (page 29)
The NITRD agencies should use, to the fullest extent practicable, available authorities and resources to facilitate the transfer of research results into practical application and commercial products.

Chapter 4: Technical Priorities for Networking and Information Technology Research and Development

Recommendation #6 (page 33)
The NITRD Subcommittee should develop and implement a Federal Plan for coordinated multiagency R&D in high-confidence NIT systems connected with the physical world to maximize the effectiveness of Federal investments and help ensure future U.S. competitiveness in these technologies.

Recommendation #7 (page 35)
The NITRD Subcommittee should facilitate efforts by leaders from academia, industry, and government to identify the critical issues in software design and development and help guide NITRD planning on software R&D.

Recommendation #8 (page 37)
The Interagency Working Group on Digital Data, in cooperation with the NITRD Subcommittee, should develop a national strategy and develop and implement an associated plan to assure the long-term preservation, stewardship, and widespread availability of data important to science and technology.

Recommendation #9 (page 38)
A key element of the Federal Plan for Advanced Networking Research and Development should be an R&D agenda for upgrading the Internet. To meet Federal agency needs and support the Nation's critical infrastructures, the Plan should include R&D in mobile networking technologies and ways to increase network security and reliability.

Recommendation #10 (page 40)
The NITRD Subcommittee should develop, implement, and maintain a strategic plan for Federal investments in HEC R&D, infrastructure, applications, and education and training. Based on the strategic plan, the NITRD Subcommittee should involve experts from academia and industry to develop and maintain a HEC R&D roadmap.

Recommendation #11 (page 42)
The Federal NIT R&D agencies should give greater emphasis to fundamental, longer-term CSIA R&D and the infrastructure for that R&D.

Chapter 5: The Networking and Information Technology Research and Development Program

Recommendation #12 (page 50)
The Director of the Office of Science and Technology Policy should take steps to ensure broad and vigorous agency involvement in the NITRD Program, given its critical importance to national security and economic competitiveness.

Recommendation #13 (page 50)
The NITRD Subcommittee should develop, maintain, and implement a cohesive strategic plan for the NITRD Program.

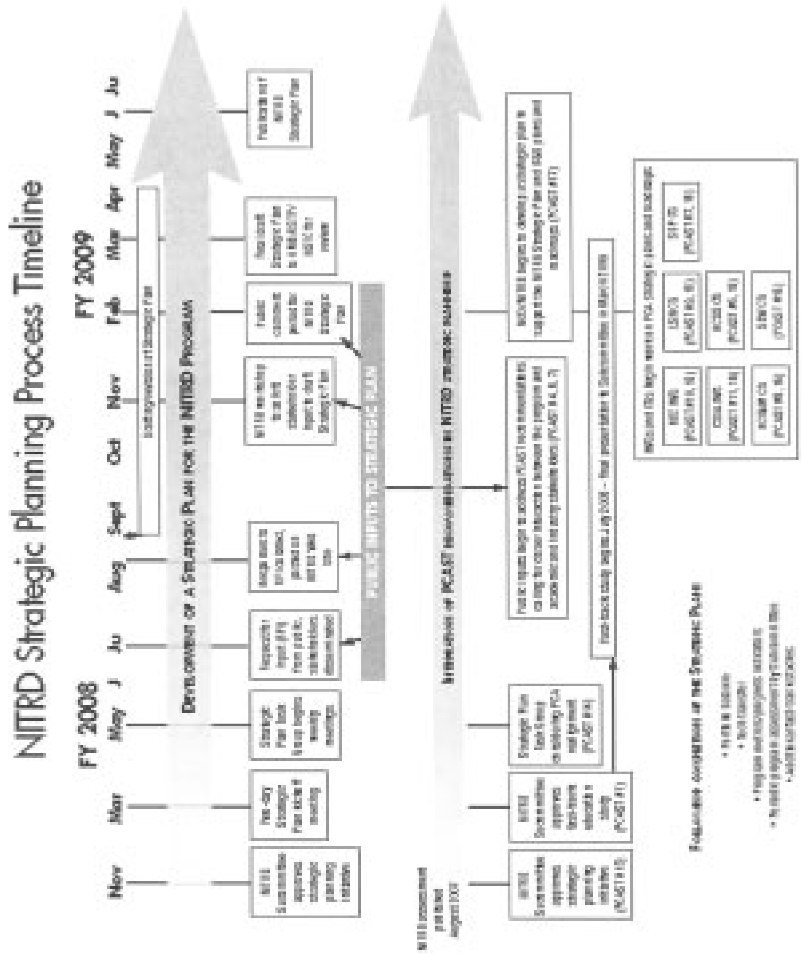
Recommendation #14 (page 51)
The NITRD Subcommittee should conduct periodic assessments of the NITRD PCAs, restructuring the NITRD Program when warranted.

Recommendation #15 (page 51)
The NITRD Interagency Working Groups and Coordinating Groups should develop, maintain, and implement public R&D plans or roadmaps for key technical areas that require long-term interagency coordination and engagement. The plans and roadmaps should be developed under the guidance of the NITRD Subcommittee and be aligned with the NITRD Program's strategic plan.

Recommendation #16 (page 52)
The NITRD Subcommittee, with support from the NITRD NCO, should develop a set of metrics and other indicators of progress for the NITRD Program and use them to assess NITRD Program progress.

Recommendation #17 (page 53)
Under NITRD Subcommittee guidance, the NITRD NCO should develop and implement a plan for supporting the development, maintenance, and implementation of the NITRD strategic plan and R&D plans.

Appendix 3: NITRD Strategic Planning Timeline



BIOGRAPHY FOR CHRISTOPHER L. GREER

Dr. Chris Greer is Director of the National Coordination Office (NCO) for the Networking and Information Technology Research and Development (NITRD) program. The NCO/NITRD mission is to formulate and promote federal information technology research and development to meet national goals. The NCO reports to the Office of Science and Technology Policy within the Executive Office of the President. Dr. Greer is on assignment to the NCO from his position as Senior Advisor for Digital Data in the NSF Office of Cyberinfrastructure. He recently served as Executive Secretary for the Long-lived Digital Data Collections Activities of the National Science Board and is currently Co-Chair of the Interagency Working Group on Digital Data of the National Science and Technology Council's Committee on Science. He is also a member of the Advisory Committee for the National Archives and Records Administration's Electronic Records Archive and a member of the Digital Library Council of the Federal Depository Library Program.

Dr. Greer received his Ph.D. degree in biochemistry from the University of California, Berkeley and did his postdoctoral work at CalTech. He was a member of the faculty at the University of California at Irvine in the Department of Biological Chemistry for approximately 18 years where his research on gene expression pathways was supported by grants from the NSF, NIH and the American Heart Association. During that time, he was founding Executive Officer of the RNA Society, an international professional organization.

Chairman GORDON. Right on the money, Dr. Greer. Dr. Reed, you are up.

STATEMENT OF DR. DANIEL A. REED, DIRECTOR, SCALABLE AND MULTICORE COMPUTING, MICROSOFT CORPORATION

Dr. REED. Good morning, Mr. Chairman and Members of the Committee. I am Dan Reed. I am Chair of the Board of Directors of the Computing Research Association and Co-Chair of the PCAST Subcommittee that produced the 2007 NITRD Program Assessment.

Today I would like to make five points regarding the NITRD Program followed by a set of specific recommendations for the future. Information technology, as Dr. Greer noted, is driven by basic research investments that has transformed our society and our economy. Imagine a world without personal computers, without mobile devices or the Internet, without predictive computational models or deep—the future can be even more amazing if we sustain our IT research——

Historically, the diversity of the NITRD agencies has been a major strength of U.S. IT research, fostering multiple approaches to complex problems. The Internet began as a DARPA project, grew with NSF support, and blossomed with commercial funding. The human genome project was a triumph of biomedicine and IT based and building on funding from NIH, from DARPA, from NSF, the Department of Energy, and it birthed personalized medicine.

This brings me to the issue of balancing risk and protection—today I believe the NITRD ecosystem's health is threatened due to an over-dependence on a single-funding source and inadequate research funding overall. DARPA's retreat from fundamental computing research at U.S. universities has unbalanced the NITRD ecosystem. NSF now provides 86 percent of all academic IT research funding, and fierce competition has driven researchers to focus excessively on short-term, well-risked research projects. Like a stock portfolio, our long-term success depends on balance, planning, and regular reassessment.

This leads to my third point, NITRD coordination and planning. In general, I believe the NITRD Programs effectively foster informal communication and coordination among the agencies, and I commend the National Coordination Office for its role in this aspect. However, the focus on individual agency agendas has made the NITRD Program less effective in managing coordinated projects, particularly multi-disciplinary ones of rising importance.

This leads to my fourth point about research opportunities and foci. In 2007, PCAST revisited the priority areas identified by PITAC in 1999. Concluding that they remained deeply relevant, including I should add, as a personal anecdote, high performance computing, something which I have been involved in for many years. IT systems that interact with the physical world, however, a special case is the more general issue of software systems emerged as a new top priority. These cyber-physical systems embed computing, sensors, and actuators and objects that span scales from our critical national infrastructure to implanted biomedical devices. Their creation requires workers with new and ever-more multi-disciplinary skills.

That leads me to the issue of sustaining our IT workforce. Today information technology has a serious image problem. It affects our workforce quantity, its diversity, and its—many groups are working very hard to address stereotypes and create new, multi-disciplinary curricula but much work remains in this area. I believe we must also do more to retain the best and brightest international students who obtain graduate degrees here, many of whom are supported by federal research grants and contracts. Simply put, our international competitiveness depends on the availability of a qualified and diverse workforce.

This leads to my recommendations for the future. To ensure the health of the U.S. IT ecosystem, we should fully fund the America COMPETES Act. This will fuel the IT innovation engine, the fundamental research by U.S. universities and national laboratories, and further broaden STEM-based education. And I commend you, Mr. Chairman, and your colleagues for your continuing support of America COMPETES.

Second, I believe we must rebalance participation in the NITRD Program so that responsibility for fundamental research is not born excessively by a single agency. As Dr. Greer noted, I believe we must create and regularly update a strategic R&D plan and a set of associated metrics that define interagency accountabilities with a mix appropriately of project scales and—risks.

Finally, I believe we must regularly review our research investment against that strategic plan. I also believe the NITRD Program is best served by a stand-alone and active PITAC that is composed of computing experts drawn from academia and industry. I say that as someone who served on both PITAC and PCAST. Eight years between overall NITRD reviews is far too long in the information technology industry. By analogy, eight years in dog years is multiple lifetimes in the computing industry. We need to be more proactive in examining our strategy.

Mr. Chairman, thank you and this committee for your continued interest and support in the future of the NITRD Program and its

importance to U.S. competitiveness and national security. At the appropriate time, I would be delighted to answer any questions.

[The prepared statement of Dr. Reed follows:]

PREPARED STATEMENT OF DANIEL A. REED

Good afternoon, Mr. Chairman and Members of the Committee. Thank you for granting me this opportunity to comment on the federal Networking and Information Technology Research and Development (NITRD) program. I am Daniel Reed, Chair of the Board of Directors for the Computing Research Association (CRA). I am also a researcher in high-performance computing; a member of the President's Council of Advisors on Science and Technology (PCAST); the former Head of the Department of Computer Science at the University of Illinois at Urbana Champaign; and currently Director of Scalable and Multicore Computing Strategy at Microsoft.

During our lifetime, information technology has transformed our society, our economy and our personal lives. Imagine a world without consumer electronics, personal computers, the Internet or predictive computational models. As Tennyson so eloquently expressed, we have ". . . dipped into the future, far as human eye could see; saw the vision of the world, and all the wonder that would be." Despite our current wonder, the future of computing—the world that can be—is even more amazing, for we are poised on the brink of even greater revolutions: deep understanding of biological and physical processes, personalized medicine and assistive living technology, autonomous vehicles that navigate in traffic and severe weather, strategic and tactical military and intelligence systems with true information superiority, information assistants that enhance our intellectual activities, distributed sensors and actuators that protect our environment, intelligent systems for advanced energy management, and a host of other innovations.

Making such visions a reality is the essence of information technology research and the core of the NITRD program. It is also why sustained and appropriate investments in information technology research and development are critical to our nation's future.

In response to your questions, I would like to make eight points today regarding the status and future of the NITRD program, beginning with a synopsis of the recent report of the President's Council of Advisors on Science and Technology (PCAST) assessment of the Networking, Information Technology Research and Development (NITRD) program.

1. PCAST: Information Technology Assessment

In 2007, I was privileged to co-chair PCAST's assessment of the NITRD program. The resulting report, *Leadership Under Challenge: Information Technology R&D in a Competitive World,*[1] was the first overall assessment of the NITRD program since that conducted in 1999 by the President's Information Technology Advisory Committee (PITAC). The 2007 PCAST report emphasized the following points:

- **NIT and global competitiveness.** Today, the United States is the global leader in networking and information technology (NIT) and that leadership is essential to U.S. economic prosperity, security, and quality of life. However, other countries and regions have also recognized the value of NIT leadership and are mounting challenges.
- **NITRD ecosystem.** The NITRD program is a key mechanism through which the Federal Government contributes to NIT research and development leadership, and the NITRD program has by and large been effective at meeting agency and national needs.
- **Research horizons and risks.** The federal NIT research and development portfolio is currently imbalanced in favor of low-risk projects; too many are small scale and short-term efforts. The number of large-scale, multi-disciplinary activities with long time horizons is limited and visionary projects are few.
- **Workforce availability and skills.** The number of people completing NIT education programs and the usefulness of that education fall short of current and projected needs. Current curricula must be re-evaluated, graduate fellowships increased and visa processes simplified to address these challenges.

[1] *Leadership Under Challenge: Information Technology R&D in a Competitive World,* President's Council of Advisors on Science and Technology (PCAST), August 2007, *http://www.ostp.gov/pdf/nitrd*_review.pdf

- **Research priority areas.** The top priorities for new funding are NIT systems connected to the physical world, software, networking and digital data, with continuing emphasis on high-end computing, cyber security and information assurance, human-computer interaction and NIT and the social sciences.
- **Strategic plans and roadmaps.** We must develop, maintain, and implement a strategic plan for the NITRD program, along with public R&D plans or roadmaps and progress metrics for key technical areas that require long-term interagency coordination and engagement.
- **Interagency coordination.** The current nature and scale of NITRD program coordination processes are inadequate to meet anticipated national needs and to maintain U.S. leadership in an era of global NIT competitiveness.

With this backdrop, the remainder of my testimony expands and explains the rationale for these PCAST findings along with personal observations on possible actions. However, the opinions expressed herein are my own, not necessarily those of PCAST or the Office of Science and Technology Policy (OSTP). I would also like to acknowledge the contributions of Peter Harsha, from the Computing Research Association (CRA), to these remarks.

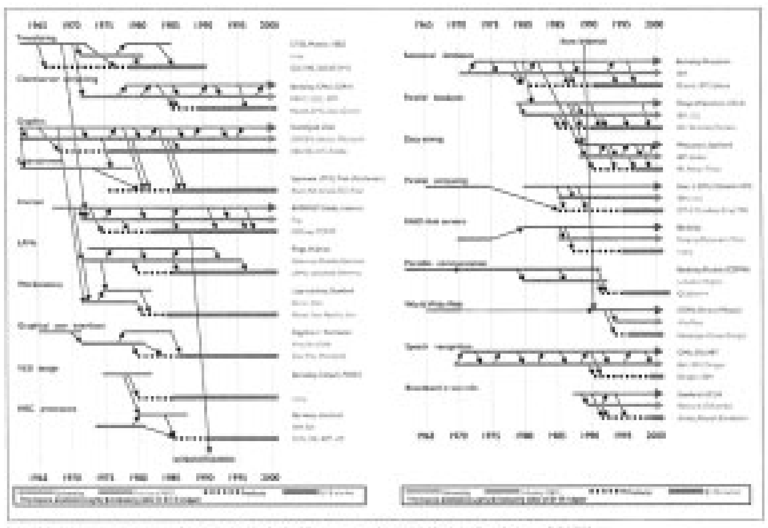


Figure 1 IT Research Transition and Impacts

2. The Importance of Information Technology

The importance of information technology (IT) in enabling innovation and powering the new economy is well documented. Advances in computing and communications have led to significant improvements in product design, development and distribution for American industry, provided instant communications for people worldwide, and enabled new scientific disciplines like bio-informatics and nanotechnology that show great promise in improving a whole range of health, security, and communications technologies. **Several studies have suggested information technology has been responsible for 25 percent of more of U.S. economic growth in recent years, despite being a much smaller fraction of the gross domestic product (GDP).**[2] **Moreover, information technology leader-**

[2] Dale W. Jorgenson and Charles Wessner, editors. 2007. *Enhancing Productivity Growth in the Information Age: Measuring and Sustaining the New Economy.* Washington, D.C.: National Academies Press. Also see Dale W. Jorgenson, Mun S. Ho, and Kevin J. Stiroh. 2005. *Productivity Volume 3: Information Technology and the American Growth Resurgence.* Cambridge, Mass.: MIT Press.

ship has proven essential to the Nation's security, from our national infrastructure and signals intelligence to our military.

Information technology has also changed the conduct of research. Innovations in computing and networking technologies are enabling discovery across every scientific and engineering discipline—from mapping the human brain to modeling climatic change and enhancing energy production. Faced with problems that are ever more complex and interdisciplinary in nature, researchers are using IT to collaborate across the globe, visualize large and complex data sets, and collect and manage massive amounts of real-time sensor-derived data.

But equally important to the role IT plays in enabling innovations in industry and in the other scientific and engineering disciplines is the role of the research and development (R&D) ecosystem in enabling IT innovations. The 1995 National Research Council (NRC) report, *Evolving the High Performance Computing and Communications Initiative to Support the Nation's Information Infrastructure,*[3] included a compelling graphic illustrating this spectacular return. The graphic was updated in 2002 and is reproduced in Figure 1.

The graphic in Figure 1 shows the development of technologies from their origins in industrial and federally-supported research, to the introduction of the first commercial products, through the creation of billion-dollar industries and markets. The original 1995 NRC report identified nine of these multi-billion dollar IT industries (the categories on the left side of the graphic). Seven years later, the number of examples had grown to 19 multi-billion dollar industries that are transforming our lives and driving our economy.

The graphic also illustrates the complex interplay among industrial R&D efforts and the interdependent ecosystem of NITRD agencies that supports academic research. Each federal agency plays a distinct, but important role in the current and future success of the U.S. information technology ecosystem.

3. The NITRD Ecosystem: Fostering Innovation via Diversity

The NITRD program is a collaborative confederation of thirteen federal agencies, each with differing missions that depend—to varying degrees—on advances in information technology. This ecosystem of agencies is complex and interdependent, with some small and others large, some supporting outcome-directed research and others supporting innovation-driven research, some supporting small projects and others funding large initiatives, some focused on federal research laboratories and others engaging academia.

Historically, this NITRD diversity has been a major strength of the U.S. approach to information technology research, as it has fostered diverse approaches to complex computing problems, with differing research horizons and communities. Together, a strong IT industry, powerful commercialization system, and high-quality education and research institutions have been critical to America's leadership in IT. The aforementioned 1995 report by the National Research Council emphasized the "extraordinarily productive interplay of federally funded university research, federally and privately funded industrial research, and entrepreneurial companies founded and staffed by people who moved back and forth between universities and industry."

To further illustrate this point, consider some specific, compelling examples of agency leadership, cross-agency collaboration and industrial engagement. The Defense Advanced Research Projects Agency (DARPA) has historically supported large-scale projects with revolutionary intent—high-speed networks for resilient communication, artificial intelligence and autonomous navigation, massively parallel supercomputing for detailed modeling, real-time and embedded systems for situational awareness—to ensure the technological superiority of U.S. military forces. **Today's Internet began in the 1960s as an ambitious DARPA (then ARPA) research project in resilient, packet-based communications for national defense.**

Reflecting its long-term focus, DARPA supported the Arpanet for well over a decade. **This later enabled the National Science Foundation (NSF) to build on a rich research and technology base to create a high-speed national network connecting supercomputing centers and their NSF-funded students and faculty researchers. From this fertile ground, the Mosaic web browser was born at the University of Illinois, spawning the commercial web revolution and today's Internet via commercial investments.**

The Department of Energy's Office of Science (DOE SC) and its National Nuclear Security Administration (DOE NNSA) have long supported algorithms and software

---

[3] U.S. National Research Council. *Evolving the High Performance Computing and Communications Initiative to Support the Nation's Information Infrastructure.* National Academies Press, Washington, D.C. 1995.

research, network and distributed systems studies and advanced computer architecture designs in both DOE laboratories and academia. **DOE SC's Scientific Discovery through Advanced Computing (SciDAC) program supports multi-disciplinary teams to develop the enabling technologies for next-generation computing systems and their application to models of climate change, efficient energy sources and biological processes.** In turn, the DOE NNSA has advanced computer systems, software and algorithms in support of nuclear stockpile stewardship and certification.

The Human Genome Project, funded by the National Institutes of Health (NIH), was enabled by high-throughput sequencing systems, based on advanced semiconductor technology and efficient algorithms for DNA subsequence reassembly executing atop high-performance computing systems. Simply put, the Human Genome Project was a collaborative triumph of biomedicine and information technology; the commercial semiconductor designs and computer architecture and academic algorithms that enabled this breakthrough were previously funded by DARPA, NSF and DOE. The tantalizing promise of low-cost, personalized medicine, with treatments and drugs tailored to individual needs, will be realized only via continued advances in computing technology, themselves derived from information technology research.

As all these examples illustrate, the success of the NITRD program has accrued from the health, diversity and vigorous interactions among its component agencies, universities and industrial partnerships. Historically, DARPA funded large-scale, high-risk projects involving academic and industry teams. In turn, DOE supported national laboratory and academic researchers around large-scale scientific instruments, and NSF supported innovation-driven research, predominantly by individual faculty members and their students, with a mix of larger projects and centers. NIH has partnered on selected NITRD programs and NASA, NIST and the other NITRD agencies have supported mission-specific research and development programs.[4]

The rich ecosystem of computing research approaches, collaborative agencies and funding models has long made the U.S. the undisputed leader in information technology, with concomitant benefits to our national security, economic competitiveness and lifestyle.

4. Research Horizons and Risks: The Funding Monoculture

In a biological ecosystem, environmental changes or the death of a species can change the ecosystem's set point or even lead to its death; the NITRD ecosystem is no different. **Today, the health of the NITRD ecosystem is threatened, and the future of our national competitiveness is at grave risk, due largely to an over-dependence on a single research funding source, a single funding approach and inadequate research funding overall.** Through the 1990s, academic computing research funding was dominated by two NITRD sources, DARPA and NSF, with each filling complementary ecosystem niches based on different project selection models, funding scales and assessment approaches.

From its inception, DARPA supported larger-scale, outcome-driven initiatives and projects based on targeted solicitations. DARPA program managers had broad latitude to assemble academic and industrial consortia that built computing technology prototypes and transferred promising prototypes into industry for commercialization. In a complementary role, NSF funded exploratory, innovation-driven computing research, funding peer-reviewed research proposals submitted by the academic community. Although project funding levels were typically lower than at DARPA, researchers were free to explore novel ideas of their own choosing. NSF researchers not only filled niches not occupied by DARPA, their most promising results often stimulated new DARPA technology prototyping and transfer initiatives.

As an example, research flourished in computer architecture, system software, programming models, algorithms and applications in the 1990s. Computer vendors launched new initiatives, parallel computing startup companies were born, and planning began for petascale systems, based on integrated hardware, architecture, software and algorithms research. This renaissance in parallel and high-performance computing research was a direct consequence of the High-Performance Computing and Communications (HPCC) program and interdependent agency initiatives, notably DARPA and NSF. DARPA funded large-scale hardware prototypes and software initiatives, while NSF supported exploratory research by single investigators.

When DARPA shifted its funding and evaluation model to shorter-term, "go/no-go" assessments and approaches, the ecosystem of funding agencies and researchers

[4] Each of the NITRD agencies supports diverse programs at multiple scales. This description captures the dominant mode of each agency.

reacted and adapted. Large-scale computing research contracted, and those academic institutions and faculty who has historically benefited from DARPA's largess turned to NSF for research funding. **This retreat of DARPA from funding fundamental computing research at U.S. universities has left a hole in the overall federal IT research ecosystem that other participating agencies have been unable to fill.** The types and scale of research changed and the number of research proposals submitted to NSF rose precipitously, with a concomitant decline in proposal success rates.

The National Science Foundation is now the predominate funder of all academic computing research. Indeed, recent analyses show that NSF provides 86 percent of all funding for academic computing research.[5] The result is that NSF is now viewed by most academic researchers as the *only* viable source of research funding. The notable exceptions are the DOE SciDAC program and those faculty members who have strong ties to the national laboratories.

The consequences of this ecosystem shift are both deep and profound, with several deleterious effects. First, fierce competition for funding has made researchers risk averse. **Today, those proposals recommended for funding are far more likely to emphasize short-term, incremental research that builds on well-understood approaches. Such proposals are less controversial and more likely to win consensus approval than those embodying high risk, ground-breaking ideas. This is especially worrisome given the timeline of Figure 1, which shows the long incubation period for these technologies between the time they were conceived and first researched to the time they arrived in the market as commercial products.** In nearly every case, that lag time is measured in decades.

Incremental advancement itself is not bad; it is the lifeblood of the scientific process. However, just as a balanced retirement portfolio includes an evolving mix of low risk, modest return investments and higher risk, higher return investments, the long-term success of our computing research ecosystem depends on a balance of modest risk, moderate payoff research and higher risk, but high payoff, revolutionary research. **We must rebalance our research portfolio to encourage greater innovation and risk taking.**

Second, current academic structures necessitate research funding as an external validation of quality and to sustain internal research processes. Hence, faculty members face enormous institutional pressure to seek external research funding for promotion, tenure and national visibility. **Because only a modest fraction of submitted proposals is funded in many programs, faculty members now spend an inordinate fraction of their time preparing, submitting and reviewing proposals.** It is not uncommon for an assistant professor to write five or even ten proposals in a single year, hoping one or two will be funded. **Hence, we must address the funding shortfall that currently limits research innovation.**

5. Research Priority Areas: Identifying Innovation Foci

The seminal 1999 PITAC report, *Information Technology Research: Investing in Our Future,*[6] highlighted the importance of software noting, "Software is the new physical infrastructure of the information age. It is fundamental to economic success, scientific and technical research, and national security." The report also noted that the diversity and sophistication of our software systems was growing rapidly at a time we lacked the technologies to build reliable and secure software systems and that even more perniciously, we were under-investing in the research needed to develop those technologies. In addition to the critical importance of software, the 1999 PITAC report emphasized the importance of adequate research investment in scalable information infrastructure and high-performance computing.

In 2007, PCAST revisited the 1999 PITAC technical priority areas, concluding that the broad areas remained deeply relevant, albeit with slight changes. Information technology systems that interact with the physical world emerged as the new top priority—cyber-physical systems where computing systems, sensors and actuators are deeply embedded in engineered objects. Such systems are now both diverse and ubiquitous and include our critical national infrastructure such as the electric power grid, mobile and human-centered sensors (e.g., mobile biomedical devices), environmental monitors and military systems. Such systems can be difficult and costly to design, build, test, and maintain and the consequences of failure can be catastrophic. However, the benefits are enormous, in-

[5] National Science Foundation, Division of Science Resources Statistics. 2008. *Federal Funds for Research and Development: Fiscal Years 2005–07.* Forthcoming. Arlington, VA.

[6] President's Information Technology Advisory Committee, *Information Technology Research: Investing in Our Future, http://www.nitrd.gov/pitac/report,* 1999

cluding more efficient transportation systems, more efficient energy generation and management and a reduced carbon footprint for a diverse set of human activities.

One should rightly view systems that interact with the physical world as a special case of the broader software priority identified by PITAC. In this spirit, software remains the second broad priority identified by PCAST, along with networking and digital data. The latter two areas reflect the popularization of the Internet, with concomitant challenges in security, scalability, resilience and management, and the explosive growth of digital data, itself enabled by inexpensive sensors and large-scale storage devices. Advances in these areas are also essential to national security and to combating cyber crime. **PCAST also recognized the need for continuing emphasis on high-end computing, cyber security and information assurance, human-computer interaction, and information technology and the social sciences.**

6. Workforce: Ensuring Quality and Quantity

In a knowledge economy, continued innovation and international competitiveness depend on an adequate and continually renewed supply of qualified and motivated workers. In the U.S., the IT workforce is composed of those educated here—U.S. citizens, permanent residents and international students—and the best and brightest from around the world who choose to live and work here. **We face both quantity challenges, ensuring an adequate supply of IT workers, and quality issues, creating curricula that match emerging technical trends and that attract and excite sufficiently diverse cross-section of the population.** As the 2007 PCAST report noted,

> *Although the overall supply of networking and information technology specialists is expected to grow in response to the growth in total demand, at current rates of enrollment and graduation, shortfalls in the numbers of highly qualified computer scientists and engineers graduated at the undergraduate and doctoral levels are likely. Women and other under-represented groups will constitute a declining proportion of the new graduates.*

The stereotype of a geek who writes code in a small cubicle and who eschews human interaction is neither reflective of the diversity of modern computing and nor of computing's role in all aspects of society, from the arts and humanities through business practice to science and engineering. Many academic, federal and private groups are working assiduously to dispel this stereotype and raise the image of computing among potential students. The *Image of Computing Task Force*[7] was created by a consortium of companies and computing professional societies to "expose a realistic view of opportunities in computing" and to "educate the public and those with the aptitude and interest to pursue computing careers, on the increasing vital role computing plays in every major field." In addition, the CRA *Committee on the Status of Women (CRA–W),*[8] the *National Center for Women and Information Technology (NCWIT)*[9] and the *Coalition to Diversity Computing (CDC)*[10] are all highlighting the importance of diversity in computing and the opportunities for creative and engaging careers.

In addition to increasing awareness of information technology as a vibrant, attractive and relevant problem-solving skill in the 21st century knowledge economy, computing professional societies and universities are working to revamp curricula that have changed relatively little since the 1970s. The changes include increasing multi-disciplinary computing education (i.e., computing and its applications to another discipline), multi-track curricula that allow students to create degree programs that better match their interests and emphasizing the power of computing as a general-purpose problem solving tool. As a complement to image education and curricula reform, PCAST also recommended increasing the number of multi-year graduate fellowships offered to U.S. students.

These image, curricula and fellowship reforms potentially address the shortfall of domestic students. However, the U.S. information technology ecosystem has long been a magnet for talented students, researchers and workers from around the world. Such individuals increasingly find attractive educational, research and professional opportunities in their home countries. **It is in the best interests of the U.S. to retain the best and brightest international students who obtain graduate degrees in this country, often supported by research grants and contracts. Hence, PCAST also recommended streamlining the process for**

---

[7] Image of Computing, *http://www.imageofcomputing.com*

[8] CRA Committee on the Status of Women, *http://www.cra.org/Activities/craw*

[9] National Center for Women and Information Technology, *http://www.ncwit.org*

[10] Coalition to Diversity Computing, *http://www.cdc-computing.org*

obtaining visas for non-U.S. students admitted to accredited graduate degree programs and to make it routine for foreign nationals who have obtained advanced degrees in NIT subjects at accredited U.S. universities to be permitted to work and gain citizenship by easing visa and permanent resident processes for them.

7. NITRD Coordination: Strategic Planning and Execution

Without doubt, the NITRD program has been effective in fostering informal communication and coordination across agencies, both collectively and via the National Coordination Office (NCO). The NCO annually solicits and reports agency spending on NITRD Program Component Areas (PCAs). **Though each federal agency is represented within a NITRD Interagency Working Group (IWG) on IT research and development, the IWG has no budget authority over any of the participating agencies or the PCAs, nor does the NCO.** Each agency controls its own budget and sets its own goals exclusively on the perceived appropriateness of that funding to the agency's mission.

In practical terms, this means the IWG function in NITRD is largely one of information sharing among agency representatives on what the agencies plan to do and have done. Although the resulting NCO data is useful, it is a retrospective view of agency decisions and priorities, rather than an assessment of program priorities and progress against those plans. The process also tends to bias the process toward incremental, agency-specific agendas, making the NITRD program less effective in managing larger-scale, coordinated projects than span multiple agencies.

In a globally competitive world, we must plan more strategically and increase agency accountability for execution against those strategic plans. This will require greater interagency coordination and collaboration across PCAs to facilitate research and development transition within and across agencies, both to support fundamental research and to enable larger, multi-agency projects.

8. Remaining Competitive: A Call to Action

To maintain the health and vibrancy of the U.S. information technology ecosystem, we must fully fund the agencies and programs included in the America COMPETES Act. I commend you and your colleagues, Mr. Chairman, for working so hard for its passage last year. It sent a powerful signal about the importance of the federal role in supporting fundamental research in the physical sciences, including information technology. I also appreciate your efforts to see the promise of the COMPETES Act realized in appropriations. **The funding authorized in the Act would help drive the core of the IT innovation engine—the fundamental information technology research in U.S. universities and national laboratories supported by the National Science Foundation, the Department of Energy's Office of Science, and the National Institute of Standards and Technology.**

The focus within the COMPETES Act on programs that aim to increase the number of students who enter science, technology, engineering and mathematics (STEM) fields is also crucial to the future of information technology research. As I noted earlier, the projected demand for IT professionals over the next 10 years—positions that require at least a Bachelor's degree in computer science or computer engineering—exceeds all other science and engineering disciplines combined. Encouraging U.S. students to enter the science and engineering education pipeline, as is the focus of many of the programs included in the COMPETES Act, will help ensure that those projected workforce needs are addressed. **The many provisions in the Act that seek to increase the participation of women and minorities in science and engineering fields—two populations that are woefully under-represented in computing—are especially important.**

Adequate funding is critically important, but it is not sufficient; this funding must be invested wisely in our information technology ecosystem. **The unilateral decision by any agency to change the direction, scope and mechanisms for its research investments has consequences across the entire NITRD ecosystem—federal agencies, universities and industry.** Such changes must not be undertaken without due consultation and consideration of broad consequences. **We must rebalance agency participation in the NITRD program so that the crucial responsibility of supporting fundamental research in computing is not borne solely by one agency.**

We must also create an interagency IT research and development strategic plan, complemented by a roadmap and a set of associated metrics that define interagency expectations and accountabilities. An evolving, strategic vision of information technology, together with an appropriate balance of short-

range, low risk and long-range, high risk projects is essential if we are to remain global leaders. **The 1999 PITAC report recommended creation of large-scale Expeditions to the 21st Century, revolutionary expeditions whose mission**

> *. . . will be to report back to the Nation what could be accomplished by using technologies that are quantitatively and qualitatively more powerful than those available today. In essence, these centers will create "time machines" to enable the early exploration of technologies that would otherwise be beyond reach for many years.*

We would do well to embrace this vision and recommendation, ensuring that we fund a mix of projects, large and small, low and high risk, and both short- and long-term.

Finally, we must also have appropriate oversight and review of our research investment and accountability against strategic plans. The President's Information Technology Advisory Committee (PITAC) was authorized by Congress as a federal advisory committee under the *High-Performance Computing Act of 1991* and the *Next Generation Internet Act of 1998,* with responsibility to assess advanced information technology and review the NITRD program. PITAC functioned as a separate Presidential advisory committee until its roles and responsibilities were assigned by Executive Order in 2005 to the President's Council of Advisors on Science and Technology (PCAST).

PCAST has a broad scope that spans all of science and technology, a challenging and important portfolio. **Given the importance of IT research and technology to our nation's economy, national security, military readiness and research enterprise, an independent PITAC is needed that can devote the time, energy and diligence to ongoing assessment of successes, challenges, needs and opportunities in information technology.** I base this opinion on my own experience as a previous member of PITAC and a current member of PCAST. Simply put, the NITRD program is best served by a stand-alone PITAC composed of computing experts from academia and industry.

In summary, information technology is a universal intellectual amplifier, advancing all of science and engineering, powering the knowledge economy, enhancing the quality of our health care, and transforming how we work, play and communicate. With vision, strategic investment and coordination, the U.S. NITRD program can and will continue to be the world's leader.

Mr. Chairman, thank you and this committee for your interest in the future of the NITRD program and its importance to U.S. competitiveness. Thank you very much for your time and attention. At the appropriate time, I would be pleased to answer any questions you might have.

BIOGRAPHY FOR DANIEL A. REED

Daniel A. Reed is Director of Scalable and Multicore Computing Strategy at Microsoft. Previously, he was the Chancellor's Eminent Professor at the University of North Carolina at Chapel Hill, as well as the Director of the Renaissance Computing Institute (RENCI), which explored the interactions of computing technology with the sciences, arts and humanities. He formerly held the Edward William and Jane Marr Gutgsell Professorship at the University of Illinois at Urbana-Champaign, where he was Professor and Head of the Department of Computer Science and Director of the National Center for Supercomputing Applications (NCSA). At Illinois, he also led National Computational Science Alliance, a consortium of roughly fifty academic institutions and national laboratories to develop next-generation software infrastructure of scientific computing. He was also one of the principal investigators and chief architect for the NSF TeraGrid.

Dr. Reed is a member of President Bush's Council of Advisors on Science and Technology (PCAST) and a former member of the President's Information Technology Advisory Committee (PITAC). He recently chaired a review of the federal networking and IT research (NITRD) portfolio, and he is Chair of the Board of Directors of the Computing Research Association (CRA), which represents the research interests of universities, government laboratories and industry. He received his Ph.D. in computer science in 1983 from Purdue University.

Chairman GORDON. Thank you, Mr. Reed, and also thank you for pointing out the need to continue the funding for COMPETES. I think sometimes the real world out there doesn't understand the difference between authorization and appropriation, and we have

got to continue to move forward. And thank you for bringing that up.

I will also point out that in the COMPETES Act, we did change the review to two years, and we made it a stand-alone committee also.

Dr. Stewart, we would love to hear from you.

STATMENT OF DR. CRAIG A. STEWART, CHAIR, COALITION FOR ACADEMIC SCIENTIFIC COMPUTING; ASSOCIATE DEAN, RESEARCH TECHNOLOGIES, INDIANA UNIVERSITY

Dr. STEWART. Let me begin by thanking Chairman Gordon, Ranking Member Mr. Hall, Messrs. Hills and Carson of Indiana, and all Members of the House Science and Technology Committee for the opportunity to be here today.

I am Chair of the Coalition for Academic Scientific Computation, or CASC. I am offering testimony as requested by Chairman Gordon regarding the President's Council of Advisors on Science and Technology 2007 Report, Leadership Under Challenge, Information Technology Research and Development in a Competitive World. To provide context for this testimony, CASC is an educational, nonprofit organization dedicated to using advanced computing technology to accelerate scientific discovery for national competitiveness, global security, and economic success.

There are a total of 53 CASC members, colleges, and universities, and research labs in 36 states and the District of Columbia. I note that Members of the Committee represent a total of 24 states, 19 of which are home to at least one CASC member.

As stated in the PCAST Report, we must improve the networking and information technology ecosystem in the United States to maintain and extend our competitive advantage and innovation. The NITRD Program support of 13 federal agencies including DOD, DOE, DARPA, NASA, NIH, NIST, and NSF has accelerated information technology innovation and led to new insights in science, technology, and medicine. These advances have led to valuable changes in the private sector as we all know.

CASC fully supports the overall recommendations of the 2007 PCAST Report. The recommendations in that report, if well-supported by finding and executed aggressively, will contribute greatly to continued U.S. leadership in networking and information technology.

Without overarching endorsement as the key point of this testimony, CASC would like to make a few suggestions to emphasize and add to the PCAST recommendations. First, federal investment in NIT research and development will be most valuable in the long run if investment patterns in the many sub areas included within NITRD are as consistent as possible over time. The PCAST Report makes several important recommendations regarding workforce development. We agree with these recommendations and would like to suggest additional areas of emphasis. Programs that will increase the number of students who choose a major related to NIT after entering college undecided on a major and continue to strengthen and expand the emphasis on science, technology, engineering, and mathematics disciplines in primary and secondary education.

We commend Chairman Gordon and the Members of the Committee as a whole for leadership in creating and supporting the development of the STEM program. We hope you might consider expanding it to include greater emphasis on computing in the future.

CASC would also like to expand on the report's recommendation regarding a strategic roadmap for federal investments in high-end computing research and development. In addition to the recommendations made in the report, such a plan should implement methods for sustained support and maintenance of software critical to the U.S. networking and information technology agenda. This plan should also support the coordination of U.S. high-end computing facilities in a way that maximizes the total benefit to U.S. national interest by leveraging investments at the college, university, State, and regional levels in addition to federal investments.

In closing, let me return to the title of the 2007 PCAST Report, Leadership Under Challenge. U.S. leadership is indeed under challenge in many ways across the globe. As regards, networking information technology, the current challenges are without precedent. Without strong investment, the United States is at risk of losing its longstanding position of global leadership in networking information technology. The consequences of that would be catastrophic. However, the recommendations made in the PCAST Report if enacted and well-funded, will continue and extend U.S. leadership in networking information technology and fuel future U.S. global leadership and innovation generally. This will lead to continued and improved prosperity, health, and security for Americans and indeed all citizens of the world.

Thank you again for the opportunity to appear before you today. I should note that my testimony this morning has been endorsed by a formal vote of CASC members. One CASC member's voting representative was unavailable due to travel. The remaining 52 have voted unanimously to endorse my testimony this morning. I hope that these remarks have been helpful to the Committee. I am happy to answer any questions now or at any time in the future.

[The prepared statement of Dr. Stewart follows:]

PREPARED STATEMENT OF CRAIG A. STEWART

1. Background and context

I am pleased to have this opportunity to provide testimony to the House Science and Technology Committee in response to a request from Chairman Gordon. Chairman Gordon, in his letter of invitation to the Coalition for Advanced Scientific Computing, asked for comments on the President's Council of Advisors on Science and Technology (PCAST) 2007 report *Leadership Under Challenge: Information Technology R&D in a Competitive World*[1] and the merit of the recommendations therein. To provide context for this testimony, I serve as the chair of the Coalition for Advanced Scientific Computing (CASC) (*http://www.casc.org*), an educational nonprofit 501(c)(3) organization with 53 member institutions, representing many of the Nation's most forward thinking universities and computing centers. CASC is dedicated to advocating the use and development of the most advanced computing technology to accelerate scientific discovery for national competitiveness, global security, and economic success, as well as to developing a diverse and highly skilled 21st century workforce. My testimony this morning has been endorsed by a majority of the members of CASC, and represents the general consensus of opinion within CASC.

[1] President's Council of Advisors on Science and Technology (PCAST). 2007. *Leadership Under Challenge: Information Technology R&D in a[0] Competitive World. http://www.nitrd.gov/pcast/reports/PCAST-NIT-FINAL.pdf*

I also serve Indiana University as the Associate Dean for Research Technologies and the Chief Operating Officer for the Pervasive Technology Labs at Indiana University. As such, I am responsible for many of the advanced networking and information technology services provided to Indiana University researchers. Through support from the State of Indiana and Federal agencies, I am also responsible for services delivered to public and private sector researchers in Indiana and researchers at institutions of higher education throughout the U.S. I came to be involved in networking and information technology originally as a biologist. I thus value advanced technology first and foremost for what it can do practically to improve the quality of human life and our understanding of the world around us.

2. Key observations

In their letter submitting the 2007 PCAST report, Co-Chairs John H. Marburger III and E. Floyd Kvamme summarized in two sentences the challenge facing the U.S. in networking and information technology (NIT):

> "While the United States clearly is the global NIT leader today, we face aggressive challenges from a growing list of competitors. To maintain—and extend—the Nation's competitive advantages, we must further improve the U.S. NIT ecosystem—the fabric made up of high-quality research and education institutions, an entrepreneurial culture, strong capital markets, commercialization pathways, and a skilled NIT workforce that fuels our technological leadership."

CASC strongly endorses this statement and the findings and recommendations included in the report. The key summary of the past, included on page 1, that ". . .. the NITRD [Networking and Information Technology Research and Development] Program has by and large been effective at meeting agency and national needs" is correct. Indeed, the NITRD program's support of fourteen Federal agencies, including the Department of Defense, Department of Energy, and DARPA, has accelerated innovation in information technology, leading to new insights and practical, valuable changes in industry (including improved fuel efficiency, health and medical care, homeland security, and the creation of many physical devices that improve our productivity and overall quality of life).

The Community I represent fully supports the overall recommendations stated in the PCAST report. General George S. Patton stated, "A good plan, violently executed now, is better than a perfect plan next week." The findings of PCAST are—overall—spot on. It is easy to quibble over details, but in general the recommendations, if executed aggressively, would be far better than inaction or continuation with the status quo in the NITRD Program.

With that overarching endorsement as the key point of this testimony, we would like to make three additional points to emphasize and add to the PCAST recommendations regarding *investment patterns over time, workforce development, and creation and implementation of a High End Computing Research and Development plan.*

3. Pattern of investment over time

Without strong, continued, and consistent investment in networking and information technology (NIT), the U.S. will not have the administrative and technical leadership to support consistent and directed change. Government investment in NIT will be of greatest value if there is consistency in levels of investment over time. The men and women who execute the national NIT agenda represent a tremendous store of experience, skill, and knowledge. The uniform experience of CASC members is that when there are strong variations in funding in specific areas of NIT over time, lean times for particular areas of research in NIT cause skilled professionals to leave public sector NIT research. This means that years of investment by the government in developing a knowledge and experience base in individuals who desire to pursue a career in the public service sector are lost to the public sector, not to return even when funding for particular areas is subsequently restored. U.S. global competitiveness, innovation, and homeland security are thus best served by consistent and strong investment in basic NIT research; advanced NIT facilities to support advanced research and development in science, engineering, and technology; and research in developing and delivering the next generation of such advanced NIT facilities.

4. Workforce Development

The PCAST report makes several important recommendations regarding workforce development aimed at increasing the supply of professionals with Bachelor's, Master's, and doctoral degrees in NIT areas. The recommendations focus on actions

that should increase the supply of skilled NIT professionals in the U.S. in the short-term. This is critically important, and CASC supports all of those recommendations. We would like to make two suggestions for funding emphasis that are in addition to the recommendations made in the report.

Recommendation: Increase the number of students receiving a Bachelor's degree in a field related to NIT by funding programs that encourage students to explore NIT majors. An effective way to do this would be to support programs that use tele-collaboration technologies to enhance the NIT-related course offerings at small colleges and universities, particularly those that serve large populations of students from groups traditionally under-represented among NIT professionals. For example, students at Jackson State University, an HBCU (Historically Black College or University), and Navajo Technical College (a college located within the Navajo Nation) took, via teleconference, computer science courses from IU School of Informatics Professor Geoffrey C. Fox. Students who took these courses indicated that they found the classes inspirational and that they affected their career plans. This activity was enabled by relatively modest funding from the National Science Foundation. Similarly, Thomas Sterling, the inventor of Beowulf computing and a computer science professor at Louisiana State, has taught classes in high performance computing classes via tele-collaboration to students of the University of Arkansas and Louisiana Tech. Increased investment in collaborative distance education, either in absolute terms or as a relative share of the NITRD budget, would have disproportionately great long-term impact on the supply of professionals with college degrees in NIT.

Recommendation: Continue to strengthen and expand the emphasis on STEM (Science, Technology, Engineering, and Mathematics) disciplines in elementary and secondary education, so as to increase the absolute numbers and relative percentages of high school graduates who plan to enter college in an NIT-related discipline. We would like to commend Chairman Gordon for his leadership in creating and supporting the development of the STEM program. The uniform experience of CASC member organizations is that within their home states, there are areas where the educational system and social environment do not provide adequate incentive or opportunity for our young people to become excited by STEM disciplines and then acquire the primary and secondary education needed to successfully pursue an undergraduate (and then advanced) education in NIT-related areas. The PCAST report recommends steps to increase the importing of talent to the U.S. from abroad at the same time that we are losing the opportunity to develop our own talent. Each CASC institution can provide data to support this. In my home State of Indiana, for example innately bright young people in the rural southwest and urban northwest of the state are lost to the U.S. 21st century workforce because they are provided neither the inspiration nor the education that would enable them to pursue careers in NIT. We recognize that this area is beyond the statutory responsibility of NITRD, but it is important and related to NITRD and the PCAST recommendations. Chairman Gordon, we hope that you might now consider leveraging the successful STEM program by expanding it to include Computing.

5. High End Computing Research and Development Roadmap

The PCAST report makes several recommendations regarding investments in High End Computing. We endorse those recommendations and would like to expand on one of the recommendations (made on page 40 of the PCAST report):

> "Recommendation: The NITRD Subcommittee should develop, implement, and maintain a strategic plan for Federal investments in HEC [high-end computing] R&D, infrastructure, applications, and education and training. Based on the strategic plan, the NITRD Subcommittee should involve experts from academia and industry to develop and maintain a HEC R&D roadmap."

As noted in the PCAST report, such a roadmap should be based on the 2004 Federal Plan for High-End Computing.[2] Since the writing of that 2004 report, several new developments in the NIT ecosystem have taken place, creating new opportunities for increased innovation, more widespread practical benefits resulting from those innovations, and enhanced leverage of federal investments. CASC offers two suggestions regarding the plan called for in this recommendation, to be added to the bullet points listed on page 40 of the PCAST report. A strategic plan for federal developments in HEC R&D should:

[2] National Science and Technology Council. Federal Plan for High-End Computing. Washington, D.C.: May 2004, available at *http://www.nitrd.gov/pubs/2004_hecrtf/20040702_hecrtf.pdf*

- Implement methods for sustainable support for software development critical to the U.S. NIT agenda. This must include supporting creation of complexity-hiding interfaces that will dramatically expand the ability of scientists and engineers generally to leverage and effectively use HEC infrastructure.
- Support the coordination of U.S. cyberinfrastructure that maximizes the total benefit to U.S. national interests by taking best advantage of investments at the college, university, State, and regional levels, in addition to federal investments.

I would like to briefly explain these points below.

Implement methods for sustainable support for software development critical to the U.S. NIT agenda. This must include supporting creation of complexity-hiding interfaces that will dramatically expand the ability of scientists and engineers generally to leverage and effectively use HEC infrastructure. The Federal Government needs to significantly increase its investment in research, development, and sustained support of important software tools. As noted in the PCAST report, software critically important to U.S. global competitiveness is not always viable as a commercial product, yet sustaining it over time is critical to U.S. interests. Sometimes open source software development is a solution. A new approach—community source software—is emerging within universities to coordinate and leverage efforts in development of educational and financial management software. This approach may or may not be applicable to scientific software. But it is notable that a relatively modest investment by the Mellon Foundation enabled the Sakai Collaboration[3] to develop a completely new approach to sustainability of educational software. Similarly a modest investment by the William and Flora Hewlett Foundation enabled the Connexions[4] project to develop a global open and free repository for authors, instructors, and students to share and develop educational material. CASC recommends that the Federal Government investigate and support new models for scientific software sustainability in addition to those already in use.

An important new trend in HEC software environments is the concept of a Science Gateway. A Science Gateway is a web-accessible tool that provides end-to-end support for a scientific work flow, such as the prediction of tornadoes or the analysis of an earthquake or a genome. For example, one Science Gateway developed with NSF support provides an intuitive interface that allows a weather expert to select input data from Doppler radars, process multiple predictions of tornado formation using some of the U.S.'s fastest supercomputers, and produce a visualization on a laptop computer in time to send emergency warnings and save lives. Science Gateways provide this sort of sophisticated capability to scientists and engineers without requiring that such people, who have invested years in becoming experts in their own specific disciplines, also invest years in becoming expert computational scientists. Using HEC systems to predict tornadoes, analyze genomes, understand earthquakes, etc., should be as easy—for researchers who understand the underlying science—as buying a book over the Internet; identifying and understanding the critical aspects of terabytes of data should be like starting with a web-accessible image of North America and zooming in on your own back yard. For decades, national and discipline-specific agendas of a few grand challenge problems in high end computing have catalyzed innovation within the U.S. Today there are thousands of important theoretical and practical problems that can and will be solved if the HEC infrastructure of the U.S. can be made more easily usable. In addition, such complexity-hiding interfaces give undergraduate and even high school students the opportunity to use high-end computing, which will aid the STEM education and 21st century workforce development I have already recommended.

Support for development of complexity-hiding interfaces must be in addition to the much-needed investments in software development on which such gateways depend and which are already called for in the PCAST report. For example, new programming models and approaches to programming are needed to take advantage of emerging HEC architectures, particularly multi-core processors and specialized computational hardware. In addition, today's high quality (including 3D) computer displays, enhanced by research and development in visualization, can provide new tools for extracting insight from the massive streams of data now produced by digital instruments.

Support the coordination of U.S. cyberinfrastructure that maximizes the total benefit to U.S. national interests by taking best advantage of investments at the college, university, State, and regional levels, in addition to Federal investments. While the term cyberinfrastructure is not used in the PCAST 2007 report, it is useful in a dis-

[3] *http://sakaiproject.org/*
[4] *http://cnx.org/*

cussion of NIT and national competitiveness. The first usage of the term cyberinfrastructure that I can find is from a 1998 press briefing by Richard Clarke, then National Coordinator for Security, Infrastructure Protection, and Counter-terrorism.[5] The term became widely used after its inclusion in a very important report by a blue-ribbon committee commissioned by the NSF.[6] There are several definitions of cyberinfrastructure; the one I like best (admittedly developed by my group at Indiana University) is as follows:

> "Cyberinfrastructure consists of computing systems, data storage systems, advanced instruments and data repositories, visualization environments, and people, all linked together by software and high performance networks to improve research productivity and enable breakthroughs not otherwise possible."[7]

Cyberinfrastructure is indeed the foundation for innovation for our nation. Leadership class systems within the national cyberinfrastructure are funded by NITRD, and that is likely to continue for some time. However, the broad foundation for innovation will best serve the needs of the Nation if Federal leadership can aid the coordination of the collective cyberinfrastructure assets funded by NITRD agencies and those funded by other sources, including colleges, universities, states, and regional consortia. The resulting extension and leverage of Federal investment in NIT, HEC, and cyberinfrastructure would be tremendous and far-reaching, enabling the U.S. to increase its global competitiveness far beyond what would be capable on the basis of federal investment without such coordinated leverage.

6. Conclusion

In conclusion, let me return to the starting point of the PCAST report. NITRD has been tremendously important to U.S. innovation and global competitiveness, the quality of life of Americans, and the security of our homeland. CASC members endorse the recommendations contained in the PCAST report, and hope that the comments made in this testimony regarding particular areas of emphasis or addition of recommendations will be of value to this Committee as it embarks upon activities to plan for an even better future of new, important, and practical accomplishments through legislation related to NITRD.

The 2007 PCAST report is titled *Leadership Under Challenge: Information Technology R&D in a Competitive World.* U.S. leadership is indeed under challenge in many ways across the globe. As regards networking and information technology, these challenges are unprecedented. Without strong investment in NIT, the U.S. is at risk of losing its longstanding position of global leadership, and the consequences of this would be catastrophic. However, the recommendations made in the PCAST report, if enacted into legislation and well funded, will continue and extend U.S. leadership in network and information technology, and will fuel future U.S. global leadership in innovation. This will lead to continued and improved prosperity, health, and security for Americans and indeed all citizens of the world.

Thank you for the opportunity to appear before you today. I am happy to answer any questions now or at any time in the future.

BIOGRAPHY FOR CRAIG A. STEWART

Craig Stewart is Associate Dean for Research Technologies and Chief Operating Officer for the Pervasive Technology Labs at Indiana University. In these roles, Dr. Stewart oversees activities conducive to and supporting research in advanced information technology. He received his Ph.D. in Biology from Indiana University in 1988, and has held a variety of positions in Information Technology at Indiana University. His longstanding career interests are in high performance computing and computational biology. In high performance computing his areas of concentration are HPC architectures and grid computing. In the area of computational biology his areas of concentration are computational phylogenetics, computationally intensive simulation methods in systems biology, and biomedical data grids. Dr. Stewart is currently chair of the Coalition for Academic Scientific Computing.

Dr. Stewart served as guest editor for *Bioinformatics: transforming biomedical research and medical care,* the November 2004 special issue of Communications of the

[5] Press briefing by Richard Clarke, National Coordinator for Security, Infrastructure Protection, and Counter-Terrorism;; and Jeffrey Hunker, Director of the Critical Infrastructure Assurance Office. 22 May, 1998. *http://www.fas.org/irp/news/1998/05/980522-wh3.htm*

[6] Report of the National Science Foundation Blue-Ribbon Advisory Panel on Cyberinfrastructure. *http://www.nsf.gov/od/oci/reports/atkins.pdf*

[7] *Indiana University Cyberinfrastructure Newsletter,* March, *2007. http://racinfo.indiana.edu/newsletter/archives/2007-03.shtml*

Association for Computing Machinery. He has co-authored numerous papers, including *Measuring quality, cost, and value of IT services in higher education* for the 2001 American Quality Congress, *Parallel computing in biomedical research and the search for petascale biomedical applications* for Advances in Parallel Computing in 2004, and *Implementation of a distributed architecture for managing collection and dissemination of data for fetal alcohol spectrum disorders research* for Grid Computing in Computational Biology in 2006. Dr. Stewart has also presented many tutorials, including a 2005 introduction to computational biology at High Performance Computing Center, Stuttgart, Germany. He also helped lead two winning projects at the premier annual international supercomputing conference: Global Analysis of Arthropod Evolution, the 2003 HPC Challenge winner; and Using the Data Capacitor for Remote Data Collection, Analysis, and Visualization, the 2007 Bandwidth Challenge winner.

Dr. Stewart is an active participant in several federally funded grants, including: TeraGrid Resource Partners (NSF); Acquisition of PolarGrid: Cyberinfrastructure for Polar Science (NSF); the Open Science Grid (NSF/NIH); and Major Research Infrastructure: Data Capacitor (NSF).

Chairman GORDON. Thank you, Mr. Stewart. As I mentioned earlier, we are in the process of trying to gain more information. The Academy will be an important part of that information. As you know, Baron Hill is fortunately your Member of Congress, and so he will be taking a direct row on this and we want you to be a conduit for information for the Academy and for Baron to play a role in it. Thank you very much.

And finally, Mr. Don Winter.

STATEMENT OF MR. DON C. WINTER, VICE PRESIDENT, ENGINEERING AND INFORMATION TECHNOLOGY, PHANTOM WORKS, THE BOEING COMPANY

Mr. WINTER. Good morning, Mr. Chairman, Ranking Member Hall and Members of the Committee. I am Don Winter, Vice President of Engineering and Information Technology at Boeing Phantom Works. I am grateful for the invitation to speak with you on the NITRD Program, specifically those focused on cyber-physical systems.

I was impressed with the way in which these recommendations were developed, bringing stakeholders from government, academia, and industry together with a common focus on national competitiveness.

PCAST Report builds a sound case for the recommended research focus areas, including the area of specific interest to me, the cyber-physical systems.

The subject of research on cyber-physical systems or CPS is of great importance to the aerospace industry as a whole and to our nation. The use of CPS is increasing, their complexity is growing at an exponential rate. Demands for higher performance and lower cost for commercial and military systems are driving next-generation systems to be highly networked and highly dynamic in nature. Moreover, systems will need to be designed to exhibit robust and predictably safe behavior in these highly dynamic environments. Future aerospace systems will require cyber-physical systems of even greater complexity. Systems will operate with high degrees of autonomy or collaborate among themselves to achieve dramatic gains in operational effectiveness. New cyber-physical system attributes such as active resource management, dynamic scheduling, and software enabled control mode changes will be needed to support these behaviors. These emerging challenges call for cyber-

physical systems on a grand scale. Research that addresses validation and verification of the complex interactions between system modules is critical. Without advances in these technologies, the costs and risks of developing next generation cyber-physical systems of this scale may be prohibitive and have a significant impact on the industry.

Many of our systems are safety-critical and require certification by the FAA or equivalent military authority. Many of our military systems will need to support coalition operations with multi-level security requirements. Our systems must also be hardened to withstand a future cyber attack. Because of these unique requirements and the relatively small number of end systems, we do not expect to see large investment from the commercial IT sector in these technologies. In order to achieve these cross-cutting capabilities, we will need advances in design technologies such as model-based development tools and validation environments to build systems rapidly and affordably. Moreover, we will require research and product focus technology in software reuse, real-time theory, languages, and product line CPS architectures. It can be applied to many different end systems.

We have achieved some measure of progress. Over the past 10 years, Boeing has developed metal-ware based product line, CPS architectures, notably the bold stroke architecture for tactical aircraft avionics and the system of systems common operating environment are SOSCO for the future combat systems. To support our military system developments, and substantial gains in productivity were realized.

What is the way ahead? Efforts today that have been fragmented across industry and limited by internal funding constraints.

CPS investments cross multiple technology domains will require an industry level critical mass to achieve the needed result. Other industries, notably automotive, energy management and control, and medical face similar CPS trends and pressures and have expressed their desire to participate. WE need a national strategy in which long-term CPS technology needs are addressed by combined government and corporate investment. Boeing for its part can focus long-term CPS investments of collaborative research in which we provide the challenge problems and in-kind participation and government industry research consortia. Although I don't speak for them, I am confident my industry partners are willing to do the same. We also need to develop new ways to facilitate the transition of research products back into industry and into our products.

The point is critical, and again, as a matter of national competitiveness, The European Union's Advanced Research and Technology for Embedded Intelligence Systems, ARTEMIS, program is funded by a public-private investment of over $7 billion and is persuading R&D to achieve "world leadership in intelligent electronic systems" by 2016. European industry is fully partnered with government and academia in ARTEMIS. From our perspective, an active partnership of this nature in CPS is essential to reap the benefits of this advanced research. This partnership needs to reach deeper than the arm's-length approach used for industry involvement today.

In summary, we support the proposed expansion of the NITRD program's research objectives to address cyber-physical systems and we look forward to the opportunity to participate. That concludes my testimony. I would be pleased to respond to your questions.

[The prepared statement of Mr. Winter follows:]

PREPARED STATEMENT OF DON C. WINTER

Good morning, Mr. Chairman, Ranking Member Hall and Members of the Committee.

I am Don Winter—Vice President of Engineering and Information Technology at Boeing Phantom Works. I am grateful for the invitation to speak with you on this subject of research on cyber-physical systems (CPS), a topic of great importance to the Boeing Company, the aerospace industry as a whole, and to our Nation. I have a great interest in this subject because of my current position managing an annual R&D budget of over $300M and my past position as one of the founders of the Bold Stroke R&D initiative at Boeing, focused largely on advancing the state of the art in cyber-physical systems.

Boeing has a somewhat unique perspective on cyber-physical systems due to our prominent position in both the military and commercial aerospace markets. Cyber-physical systems are pervasive at Boeing, and in the aerospace industry at large. They are becoming increasingly prevalent in other sectors, notably automotive and energy management. Their importance to our products is huge and their complexity is growing at an exponential rate. Demands for higher system performance and lower system cost for commercial and military systems are driving next generation systems to be highly networked and highly dynamic in nature. Lower recurring and maintenance costs will be derived from integrated vehicle health management that enhances system reliability and reduces logistics and maintenance costs. Moreover, systems will need to be designed to exhibit "predictably safe" behaviors in an uncertain environment.

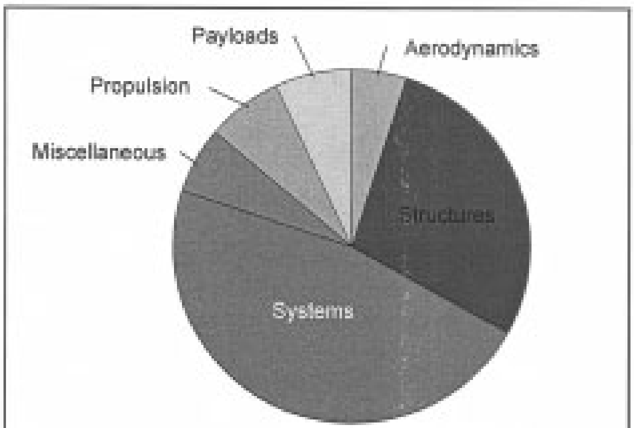


Fig. 1 - Typical Transport Aircraft Development Cost Distribution – Current Generation

In the 70's and 80's aerodynamics and structures accounted for nearly 90 percent of the development cost of a transport aircraft, with cyber-physical system development accounting for less than 10 percent. The trend has reversed, and cyber-phys-

ical system design, development, validation and certification account for nearly half of development costs for current generation system, and for next generation systems this percentage is expected to rise to 50 percent or more.

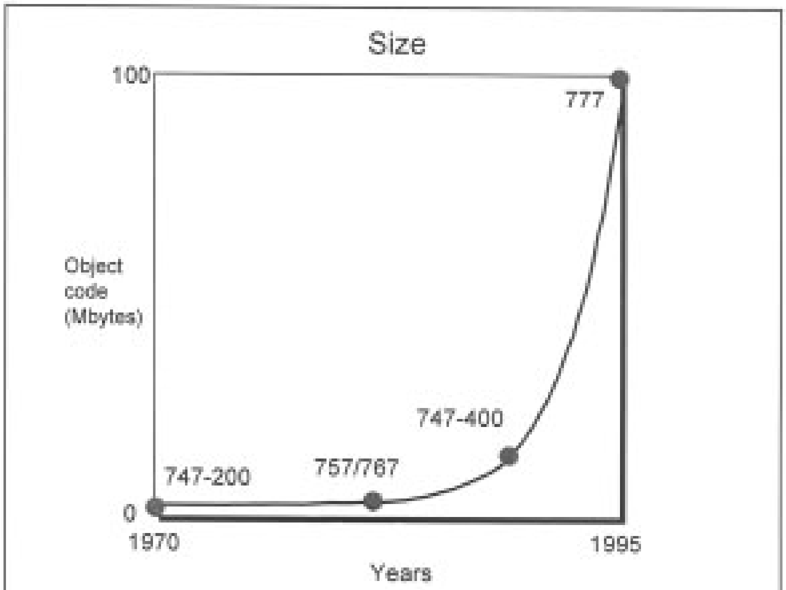


Fig. 2 - Trends in Aircraft Software Object Code Size

Several examples are germane and illustrate the exponential growth in software and system complexity of our modern systems. The 747–400 first flew in the late 1980's. The size of the software for the on-board cyber-physical systems is on the order of 10MB. The Boeing 777 first flew in the early 1990's. Its flight software size is an order of magnitude larger—100MB (on the order of 10 million SLOC). As we evolve to systems such as 787, software size and system complexity will be increased by two or more orders of magnitude.

These are cyber-physical systems on a grand scale. Research that can support validation and verification of the complex interactions between system modules is highly important. Without advances in these technologies, the cost and risk of developing next generations of cyber-physical systems of this scale may be prohibitive, and have a significant impact on the aerospace industry.

The trends towards CPS complexity are not exclusive to the aerospace industry. The automotive industry has a similar experience. For the last several years, Boeing has been participating in CPS forums across aerospace, automotive, and energy sectors. At a May 2007 CPS Roundtable, representatives from USCAR (the U.S. Council for Automotive Research—an umbrella organization for collaborative research among Chrysler, Ford, and General Motors) reported similar trends. Currently the percentage of vehicle cost due to electronics content is approximately 30 percent. The electronics content is increasing in complexity and number of functions. USCAR likewise indicated that "the most difficult issues lie not in the design of the software in individual modules, but in the interactions between different modules and components—i.e., integration of embedded systems composed of heterogeneous components designed and implemented by different suppliers."

Cyber-physical systems are pervasive in other military systems. Emerging systems (manned and unmanned) are incorporating greater intelligence and autonomy. Collaborative, network-enabled operations between multiple systems are becoming the rule rather than the exception. The CBO (published in, *"The Army's Future*

Combat System Program," April 2006) has indicated that at least 34M lines of software code, much of it for CPS, will be generated for Future Combat Systems—about twice current estimates for the Joint Strike Fighter. Today's generation of fighters (figure below) incorporate many cyber-physical systems. These systems operate in highly dynamic environments with real-time mission specific behaviors. This imposes challenges on the cyber-physical systems in the areas of networking, information management, verification, validation, and certification, to mention a few.

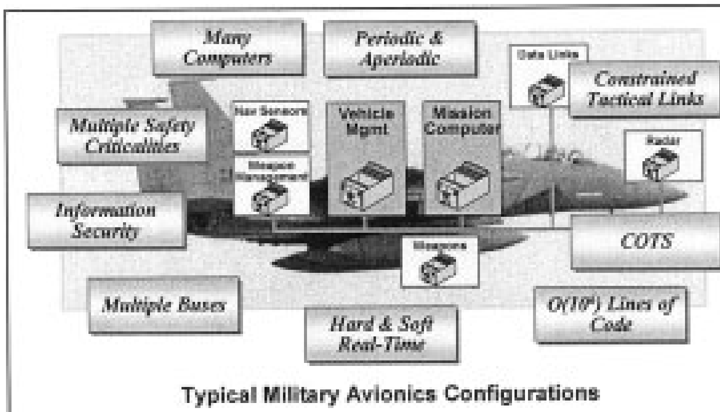


Fig. 3 –Avionics CPS Characteristics

Future aerospace systems will require cyber-physical systems of even greater complexity. Systems will operate with autonomy and will collaborate among themselves to provide vast gains in operational effectiveness. Enabling capabilities in active resource management, dynamic scheduling, and software enabled control mode changes will be needed to support these behaviors. Systems of this sort have flown today in research focused demonstrations. They will be the norm in the future.

Estimates on source lines of code for systems beyond the current generation of developing systems are several orders of magnitude higher—and will likely exceed one billion lines of code.

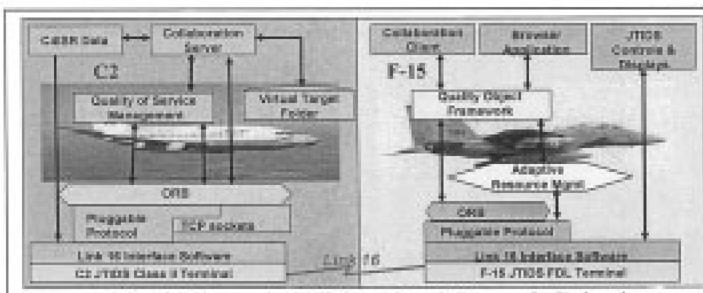


Fig. 4 - Example Collaborative & Dynamic Behaviors

Requirements for cyber-physical systems and software are far more stringent than those for typical office automation applications. Our systems must support real-time behavior. We require ultra-high reliability and many of our systems are safety critical and require certification by the FAA or equivalent military authority. While the occasional "Blue Screen" may be painful in the office environment, it can have extreme consequences in the air. Many of our military systems need to be designed

to support coalition operations with multi-level security requirements. Our systems must also be hardened to withstand future cyber attacks by adversaries. Because of these unique requirements and the relatively small numbers of systems, we do not expect a large investment from the commercial IT sector in these technologies.

In order to achieve these cross-cutting capabilities, we will need advances in technologies such as model-based development tools, methods, and validation environments to build systems rapidly and affordably. Moreover, we will require product-focused technologies including software reuse, architectures, real-time theory, languages, and product line architectures to achieve system affordability by recouping investment across multiple system developments.

We have achieved some measure of progress. Several years ago, Boeing developed middleware-based product line architectures to support our military system developments. Sizable investments were made in new CPS architectures and infrastructures (e.g., Bold Stroke and the FCS System of Systems Common Operating Environment) and substantial gains in productivity were realized. The middleware-based approach is critical since the days where military systems lead and dominate the IT industry are long past. Specifically, CPS architectures like Bold Stroke (illustrated below) were developed in part to provide layers of isolation between the avionics software for DOD systems like F/A–18 and F–15 from hardware and operating systems from the commercial IT industry.

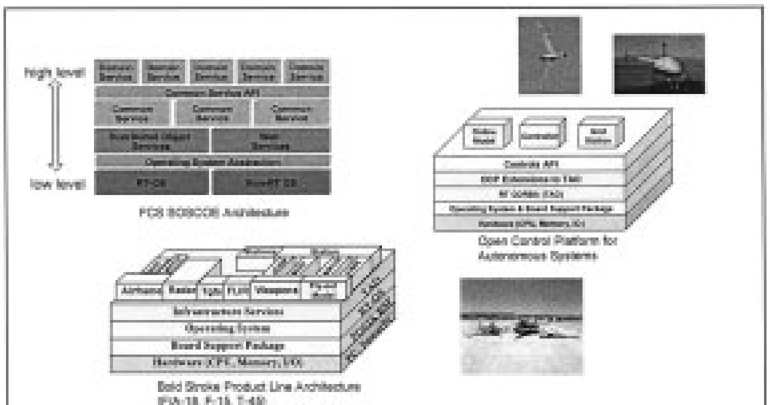


Fig. 5 – Industry-Developed Middleware Based Architectures to Provide Hardware and Software Independence for CPS

The challenges today are far greater than those faced in even the recent past and continue to grow as individual systems evolve, operate with greater autonomy and intelligence, and operate as part of a networked system of system. The challenges grow even larger with future generations of unmanned air systems operating in national air space.

What is the way ahead? Efforts to date have largely been fragmented across the industry and limited by internal funding constraints. CPS investments cross multiple technology domains and will require industry-level critical mass to achieve the needed results.

We need a national strategy in which long-term CPS technology needs are addressed by combined government and corporate investment. Boeing, for its part, can focus our long-term CPS investments on collaborative research in which we provide challenge problems and in-kind participation in government-industry research consortiums. I'm confident our industry partners are willing to do the same. We also need to develop new ways to facilitate the transition of research products back to industry and into our products. This point is critical and is a matter of national competitiveness. The European Union's (EU) Advanced Research and Technology for Embedded Intelligence and Systems (ARTEMIS) program is funded by a public-private investment (over $7B in mid-2007 dollars) and is pursuing R&D to achieve "world leadership in intelligent electronic systems" by 2016. European industry is fully partnered with academia in ARTEMIS. From our perspective, partnership be-

tween industry and academia in CPS is absolutely essential to reap the benefits of this advanced research. This partnership needs to reach deeper than the rather "indirect" approach used for industry involvement today.

In summary, we support the proposed expansion of the NITRD program's research objectives to address cyber-physical systems and we look forward to the opportunity to participate.

That concludes my testimony. I'd be pleased now to respond to your questions.

BIOGRAPHY FOR DON C. WINTER

Don has been employed at Boeing and its predecessor companies for 31 years. He holds BS and MS degrees in Physics from the University of Missouri and an MBA from Washington University. Don held a number of avionics design and systems engineering assignments on the Tomahawk cruise missile program from 1977 to 1988. He joined the Mission Planning Division of McDonnell Douglas Missile Systems Company in 1988, serving in program management roles on the Tomahawk Mission Planning Upgrade and (UK) Automated Mission Planning Aid (AMPA) programs, 1988–91. In 1992 he was named Deputy Program Manager for the USAF Air Force Mission Support System (AFMSS). In 1995, he joined the Production Aircraft Advanced Design organization as Manager—Mission Systems, and founded the Common OFP initiative, which later served as the foundation for the Bold Stroke advanced avionics program. He led CRAD programs under the Phantom Works Open Systems Architecture technology thrust from 1998 to 2001, when he became Director of the overall thrust. He then led the PW Network Centric Operations thrust, focused on the development of key technologies and tools for network enabling Boeing systems and products, from its inception in 2003 through mid-2005. Don then assumed leadership of the Integrated Command and Control organization within the C3ISR Solutions business segment of Boeing Integrated Defense Systems. In this capacity Don led the development and execution of C2 market shaping, product development and business pursuit strategies. Most recently, Don returned to Phantom Works to lead the Engineering and Information Technology organization, a team of 1,000 engineers and scientists performing leading edge research spanning domains ranging from aeronautics and propulsion to avionics, sensors and advanced information technology. Don has authored numerous technical publications and currently serves on advisory boards at the University of Cambridge, the University of California–Berkeley, Vanderbilt University and Washington University.

DISCUSSION

Chairman GORDON. Mr. Miller, as you know, the PCAST top recommendation was the cyber-physical security, and we do want to get more involved in that.

At this point we will open the first round of questions. The Chair recognizes himself for five minutes. What I would like to do is I have a couple of questions just to put to the panel in general, and the first is the PCAST assessment of NITRD program indicates that it should rebalance the funding portfolios by increasing support for important problems that require large-scale, longer-term multi-disciplinary R&D, increasing emphasis on innovation and therefore high risk but potentially higher payoff expirations. Do you agree with this recommendation? If so, what should be done to implement support for such large-scale innovative research projects? Dr. Greer, why don't we start with you?

Dr. GREER. Thank you, Chairman. I think we would agree with that recommendation of the PCAST assessment that these investments in high risk but high payoff in multi-disciplinary undertakings are important, critical in the current IT landscape. As I said, our strategic plan focuses on identifying challenges that can only be approached by agencies working together and the corresponding technical issues to achieve that.

Chairman GORDON. And can you do that on existing funding or does that require additional funding?

Dr. GREER. I think we would look to both of those possibilities, that refocusing some existing funding on these shared projects, identifying those things that would substantially enable an agency's mission if it could be accomplished. Then that merits some focusing of funding. There may be other opportunities for added funding in that same category.

Chairman GORDON. Will you be identifying those areas of opportunities and funding?

Dr. GREER. Yes, that is part of our strategic planning process to look for what are the categories of this type, the multi-agency, higher-level challenges that could be taken on by a joint effort across agencies in which the missions of the individual agencies are supported by this joint effort.

Chairman GORDON. Would anyone else like to comment on that? Okay.

Dr. REED. Well, I should say I hope I agree with the commendation in this case since I helped write it. Just a reminder that the PCAST was not the first time that this observation has been made. If you go back and you look at the 1990—report, the last systemic evaluation of the program, it recommended something quite similar, something that was called out as expeditions to the—intended to be large-scale integrated investments—technology that could have a transformative effect. And I agree with Dr. Greer, it will be quite a mix of targeted reallocation and most likely some additional investment.

Chairman GORDON. Has this recommendation been made before or are they behind the curve on getting something done?

Dr. REED. There were responses to those recommendations, perhaps not at the scale that the original recommended, some due to some financial constraints. I think it is difficult to change the culture of investment because again, it is not just an agency response, it is a community response to the changes that the Federal Government induces. And there are strong incentives among the community to continue in many cases the status quo. So it is not just a government issue, it is a community education issue about the—and the risk of——

Chairman GORDON. I only have five minutes also, so let me get to my second question. PCAST also recommended that NITRD Program provide increased support for research on software but does not cite specific research needs where the current program is deficient. Software is a perennial area of weakness, and information technology and an area in which NITRD Program currently allocates resources. What is missing is software research resources limited or idea limited? And what research is needed to make greater progress for improving the capabilities and reliable software. And I think, Dr. Reed, we should probably start with you on that one.

Dr. REED. I think it is a question of scale, and to hark back to something that Mr. Winters said, as an example, cyber-physical systems. What is happening is our software systems are growing exponentially in size and complexity but perhaps even more worrisome is that they are not isolated. They can control our physical environment in all kinds of day-to-day ways, from national infra-

structure to our personal experiences. And the search portfolio, back to the previous question, I think the challenge is to look in at how we address software at large scale. There is lots of research on the small-scale software issues but how to deal with large, complex systems where a small group is unlikely to understand its behavior, its reliability, and its dynamics. There are some deep research issues there. Some innovation is required. There are questions frankly we don't know the answers to. It is not even in some cases clear how to approach solutions to the problems.

So the basic research, but there is also a scale issue about approaching a problem that is challenging at the moment in academics.

Chairman GORDON. If I can ask, and I will try to be quick with this, this is the situation we run into so often is there is simply not enough money being invested. Now, we can get into, you know, what are best parties, that sort of thing. I think we need to do it through efficiencies in two ways. Certainly the interagency is an excellent approach, and I compliment what you have done. The second is whether or not these are appropriate areas for international cooperation. You know, what is our parochial interest here or first to market interest versus international collaboration in terms of trying to bring some economy to the research? Would you all give me some quick thoughts on that?

Mr. WINTER. I will give a couple of thoughts. I think that we have examples already of international cooperation in our business in areas considered to be infrastructure issues versus, you know, areas of proprietary or competitive advantage. We are not in the software business or the IT business. Fundamentally, we are in the system business, the aerospace system business. And we believe areas such as cyber-physical system, infrastructure investment, is something we are willing to do in a collaborative basis with our competitors, with academia, and with international——

Chairman GORDON. Well, let me ask you a quick question again. Is there any existing vehicle for that type of collaboration now, any multinational agency or anything that you know of? Dr. Greer.

Dr. GREER. This is an important question. There are areas of NIT that are inherently international. The Internet itself is global. Cyber security is a global issue. In each of those areas, an area of large-scale networking, for example, there are a series of organizations that manage the standards development that manage the network operation and so on. So in each of those separate areas, there are international organizations. I think the challenge is in coordinating across those international bodies, particularly in the area that Dr. Reed has described, fundamental research, the software science, the theory of mathematics.

Chairman GORDON. My time is up, but I would like for you if you have an opinion to respond to us again in this aspect of limited resources but not limited needs, where you think there might be areas for international cooperation, you know, where they are already going on, those other agencies, and should there be, you know, whatever coordinated body. In other words, how can we get better bang for our buck here without harming ourselves in a first to market or proprietary way.

Thank you, and excuse me, Mr. Hall, for taking a little time there. You are certainly recognized.

Mr. HALL. You are the Chairman. Mr. Winter, you mentioned ARTEMIS. You mentioned the need for the United States to have something similar to the EU public/private partnership, research, technology, and so on and so forth called ARTEMIS. Although termed an EU program, isn't it true that industry contributes more than half of the funding for this and was responsible for the total start-up and operational costs of ARTEMIS? Is that true?

Mr. WINTER. Yes, this is under the European Framework Program which is a model for collaborative government, private-sector investment.

Mr. HALL. Do you think the U.S. industry would commit to the same level?

Mr. WINTER. Yes, I do.

Mr. HALL. Would Boeing?

Mr. WINTER. Yes.

Mr. HALL. Dr. Reed, would Microsoft?

Dr. REED. Microsoft already is in many areas, so I have no doubt about that.

Mr. HALL. You think our own industry is up to funding at a greater extent?

Mr. WINTER. I think we are already doing it to a large degree and it is a matter of coordination, being provided by nationally led activity, supplemented by some public funding for the academic sector. I think it is more of a matter of channeling investments we are already making.

Chairman GORDON. Mr. Hall, you raised a very good point. Could you also respond to the Committee on how we could do that, your suggestions in that area? I think Mr. Hall raises a very good point. Thank you.

Mr. HALL. Do we await that? Oh, no, no.

Chairman GORDON. No response. They will get it to us in writing.

Mr. HALL. All right. Okay. I think my time is up. I yield back.

Chairman GORDON. Mr. McNerney is recognized for five minutes.

Mr. MCNERNEY. Thank you, Mr. Chairman. First of all, I want to remark on a comment Dr. Stewart made. You recommended consistent federal funding, and I just want to say that I feel your pain on this. I spent my career in the renewable energy business, and the production tax credits came and they went and the industry suffered immensely from those cycles. And I am sure that federal funding on a consistent basis would be better than just about anything else. But then I also echo the Chairman's words on this, we can authorize all we want in this committee. If there is not enough money in the kitty, it is not going to happen. And so Dr. Reed mentioned that 86 percent of the funding is coming from one single federal agency, and that has its advantages because it allows better coordination but it has a disadvantage. I didn't quite understand what the disadvantages were if you would elaborate on that a little bit, Dr. Reed?

Dr. REED. Certainly. Historically as I said, the diversity of agencies had different approaches, and by nature of the agencies and because they have differing missions and often there is a pipeline

of technology process and research that leads to its impact in commercial industries. If you look, for example, at some of the major technologies that we take for granted now, there is about a 20-year pipeline from basic research until they become billion dollar or more industries. But in the federal context, that often meant a curiosity driven, single investigator research cannot get by, researchers are typically academia funded by the National Science Foundation. DARPA on the other hand tended to focus on much more goal-directed outcomes, larger scale projects, building advanced prototypes in collaboration with industry. But it built on ideas that had often been explored years before by researchers funded by the National Science Foundation. So that interplay of agencies meant that there were different ideas that could be picked up and explored with different mechanisms. It goes back to the interagency collaboration, coordination mechanism, how that diversity created a variety of approaches to innovation. And what has happened is we have lost some of that diversity. It certainly in the academic side—on that as opposed to broadly.

And so we only have the first order a single approach in academic circles—that has been largely a single faculty member.

Mr. MCNERNEY. You were talking about sort of an agenda. If it is a single agency, it tends to be agenda driven rather than giving a diverse set of rules?

Dr. REED. Right. You would like multiple goals, multiple agendas, multiple kinds of approaches to select projects for funding because that leads to different mixes of people, different kinds of outcomes, and we have moved much more toward a single kind of outcome model where it had been a much more diverse model.

Mr. MCNERNEY. It seems to me that if you have a well-run program within the NSF, it would accomplish those objectives rather than to try and coordinate different agencies.

Dr. REED. It's a balancing act for sure, and I am sure Dr. Greer can speak to that as well who balances that process. But each agency has a different culture, and its culture makes it easier or more difficult for it to do certain things. Some things are much easier to do in a Defense Department model, some things are much easier to do in a NSF-style model. And it is that culture that the agencies struggle with when we try to foster interagency collaboration and agency agendas versus the broader sort of integrated agency and defense IT research.

Mr. MCNERNEY. Okay. Thank you. Mr. Winter, I am interested in your discussion of cyber-physical systems. Could you elaborate a little bit on the current threat? What does that look like, how immediate is it, do we have tools to move forward aggressively on that?

Mr. WINTER. You are referring specifically to cyber attack on——

Mr. MCNERNEY. Physical cyber attack, yes.

Mr. WINTER. Cyber-physical systems are what we used to call embedded systems, traditionally very isolated and stand-alone entities. Apply control computer in an aircraft, for example, wasn't subject to any external influence or attack. As these systems evolve to a more collaborative model where they are not only doing hard real-time business on board the platform but are also participating as clients in a network, they become vulnerable to cyber attack,

tampering. The science for cyber security for cyber-physical systems is really in its infancy. Because the systems have only recently been sort of opened up and made accessible because of their need to again service clients on network, we are just in the early days of beginning to really take on the cyber attack threat for these kinds of systems.

Mr. MCNERNEY. Well, I guess my time is expired, so I will yield back.

Chairman GORDON. The gentleman's time has expired, and Ms. Edwards is recognized.

Ms. EDWARDS. Thank you, Mr. Chairman. Just one question. I mean, each of you raised the issue of technical capacity, training, where are the professionals for the future, and going to this question around cyber security, I read an article yesterday about the use of virtualization, particularly in the retail industry. And I wonder what the impact is, specifically as you just mentioned, Mr. Winter, of the idea of virtualization in these systems where you are trying to achieve efficiency and, you know, monitor operations but how vulnerable does that leave us to cyber attacks and what capacity do we have to address emerging issues in technology? It just seems like there is one every day around security. What is the capacity we have right now to address those emerging issues given the lack of capacity in the industry and in the federal sector?

Mr. WINTER. I think we do have a capacity issue. Information assurance specialist is one of the most sought-after and rare commodities from a field personnel standpoint in our industry. We have a few, and we bend over backwards to keep them with us. It is a small and slowly growing pool of specialists, and I think the lack of collective training and a qualified workforce in that area is a real threat to our business. And to many other business, the financial sector, other aspects of our national IT infrastructure.

Ms. EDWARDS. Dr. Reed, do you have a——

Dr. REED. Oh, I have to agree with Mr. Winter. There is a shortage of talent in this area, and as I said, because so many of our everyday objects now include embedded intelligence and network connections, there are substantial challenges here. Microsoft, for example, has made trusted computing a major initiative, to look at how to make software more robust because as you have observed rightly, it is subject to a wide range of attacks every day. Part of this is an inevitable consequence that software permeates almost everything, but it is also an absolute hard fact of the original question that Representative Gordon asked about the challenges we face in building large complex infrastructure and the underlying research issues behind those. This is one example of the manifestation of that struggle to build systems from first principles that are reliable and secure, and the struggle is to retrofit security systems as we discover vulnerability. But there are major research issues here, workforce issues, and other venues people have testified, and there are new programs to advance the state of cyber security research under way now but there is a lot of work to do without that.

Ms. EDWARDS. And so then to each of you, I mean, how do you then prioritize where the allocation needs to go for research and development, what areas, because it seems very expansive and you

know, it is clear from your earlier testimony, obviously we haven't been able to fund everything and we won't.

Dr. STEWART. Funding everything is clearly beyond reason, but I do think it is important to break up the funding portfolio and look at it in terms of a variety of topics. Cyber-physical systems, basic research and networking, research networks in support of research in other areas cyber infrastructure, production cyber infrastructure delivered today, and the development of new cyber infrastructure for tomorrow. And the threads of those research and development activities need to go on continually so that the expertise that we build up which is so precious gets retained in these programs, and then while building the better workforce is, you know, a 20-year process, from a 10-year-old to a 30-year-old seasoned professional, looking at the long range and really focusing on, okay, we recognize that today there shortages of workforces. There are short-term measures that can be put into place that will aid that in the short run, but really fundamental efforts as Dr. Reed has already mentioned have to be put into encouraging young people in the United States to pursue careers in networking information technology.

Ms. EDWARDS. Thank you, Mr. Chairman.

Chairman GORDON. I thank you for your value added, Ms. Edwards, you bring to our committee.

Mr. Hill, you are recognized for five minutes.

Mr. HILL. Thank you, Mr. Chairman, and I want to thank the panel members for being here this morning, in particular Dr. Stewart, who is not only chairman of CASC but is also the Associate Dean at the greatest university in the history of the world, Indiana University. Dr. Stewart, it is great to have you hear today. Dr. Stewart, you mentioned in your testimony the importance of consistency, and I want to return to that issue. Are you suggesting that there are inconsistencies in funding that are occurring?

Dr. STEWART. I think if you look back at the past several years of funding in NITRD as implemented by the participating agencies, there have been recognitions of areas where additional funding is needed, and funding has been propped up in one area at sometimes the expense of other areas; and that oscillation in funding really creates difficulty in maintaining the expertise base among people who really desire to pursue a career in publicly funded networking information technology research. If a program is eliminated or funding is temporarily suspended and a person leaves publicly funded, publicly oriented network information technology research, they are not likely to come back. That expertise is lost, and expertise as we have heard from I believe all four of us this morning is tremendously valuable.

Mr. HILL. And this is happening?

Dr. STEWART. This has happened. Yes. Very definitely.

Mr. HILL. Okay. Switching gears then, one recommendation you make is to increase the coordination between federal agencies. How would you suggest that we do this or how would you suggest this be done?

Dr. STEWART. Well, I think the key point is to add to the coordination between federal agencies and add to that more coordination colleges and universities, State investments and regional investments, and the Coalition for Academic and Scientific Computation

and the Educause Campus Cyberinfrastructure Working Group just held a workshop last week in Indianapolis to generate new ideas specifically on this topic. As Dr. Reed said, a lot of these issues have to do with the culture of academia, and I think one of the key points is to make recommendations both to academia and State-funded R&D activities that enable them to better collaborate with federally led initiatives and to add to the federally led initiative ways that will allow that collaboration to make it more effective.

Mr. HILL. Well, could the NITRD planning in coordination mechanism be used as a forum for this broader level of coordination?

Dr. STEWART. I do indeed. I think that is actually the best way to begin that.

Mr. HILL. Thank you, Mr. Chairman, I yield back.

Chairman GORDON. Well, before we thank our witnesses, I just thought I would check and see if anyone wants to have an alternative opinion as to the world's greatest ever colossal university. Dr. Baird.

Mr. BAIRD. I would just point out I am proud to have two representatives from the great State of Washington here and let that speak for itself.

Chairman GORDON. Again, I want to thank our witnesses. We are trying to build a base of information. You have given us a good place to move forward. We would hope that you would respond to those questions that we ask as well as anything else. As we go through this process, you know, there are a few of us here but there are hundreds of thousands, if not—we normally have a couple of million that watch our webcast, so there are lots of others that are out there, and we want to welcome any suggestions to this very important concern. And this hearing is adjourned.

[Whereupon, at 10:56 a.m., the Committee was adjourned.]

Appendix:

ANSWERS TO POST-HEARING QUESTIONS

ANSWERS TO POST-HEARING QUESTIONS

Responses by Christopher L. Greer, Director, National Coordination Office for Networking and Information Technology Research and Development (NCO/NITRD)

Questions submitted by Chairman Bart Gordon

Q1. Are there areas of IT research that are good candidates for international cooperative efforts that would leverage U.S. investments but would not otherwise harm U.S. competitive advantages, such as being first to market for a new technology? What mechanisms are available, or could be instituted, to facilitate such international cooperative research?

A1. Because we live in a global digital society there are international implications across all areas of networking and information technologies (NIT). However, international cooperation is exceptionally important in four NIT areas.

1) Long-term data preservation and access/sharing

This is a vital area for international cooperation, both because 21st century science is global and data-driven, and because many of our society's challenges (e.g., energy and other natural resources, climate change, biodiversity, and human health in a globally-connected world) require coordinated international data sharing and analysis.

Current NITRD examples:

a) DOE/SC and NSF support international high-energy physics research, including analysis of gigabytes-per-second data from the Large Hadron Collider (LHC) located at the CERN site near Geneva. This includes high-capacity optical network links to two tiers of U.S. analysis sites and development by DOE/SC of new and extended protocols enabling massive data throughputs across broadband network links.

b) The NSF-supported Very Long Baseline Array (VLBA) of telescopes cooperates with the European VLB Network to create a global Internet telescope with unprecedented resolution for distributed near-real-time observation and data gathering.

Possible NITRD cooperative partner on data issues:

The mission of the International Council for Science (ICSU) Committee on Data for Science and Technology (CODATA) is "to promote, throughout the world, the evaluation, compilation and dissemination of data for science and technology and to foster international collaboration in this field." The U.S. National Committee for CODATA links the scientific and technical community in the United States and the international CODATA on data issues and operates within the National Research Council's Board on International Scientific Organizations. I have met several times with USNC CODATA to share plans and information and look to strengthening that link as a conduit for international partnerships in the data arena.

2) Advanced networking

International networking cooperation is a prerequisite for seamless global high-speed communications, including scientific data sharing. The NITRD agencies thus have longstanding cooperative relationships with international networking organizations and the scientific networks of other countries, and continue to expand these partnerships.

Current NITRD examples:

a) The September 28–30, 2008 Networking Research Challenges Workshop (with international participants from the Netherlands, Canada, Japan, South Korea, and China), will be held in conjunction with a meeting of the Global Lambda Infrastructure Federation (GLIF), which coordinates international cooperation and transparency among the world's optical networks. One of the key goals of this workshop is to explore the international implications of the recently-developed Federal Plan for Advanced Networking (see *www.nitrd.gov/ITFAN-preprint-061108.pdf*).

b) NSF's International Research Network Connections (IRNC) program, includes

a) The TransPacific Network (TransPac) providing connectivity among Asia, Europe, and the U.S.;

b) PerfSonar, a global collaboration among national research and education networks in the U.S., Europe, Latin America, and Asia that is developing a distributed network measurement framework to improve end-to-end performance for researchers; and

c) the Pakistan-U.S. Research & Education (R&E) Network connection, online as of August 15, which connects Pakistan's scientific research and education community for the first time to the U.S. and global R&E networking fabric (also supported by the European Union's TEIN2 project).

c) NSF, through its Network Science and Engineering program, has been working with the U.S. academic and industrial communities to create opportunities for possible federation of experimental network infrastructure, participating in the National Institute of Information and Communications Technology (NICT) JGN2 and AKARI (Japan's new generation network testbed) Symposium in Tokyo in January 2008 and the Future of the Internet Conference in Slovenia in March 2008. NSF staff will participate in the launch of the EC's Future Internet Research and Education (FIRE) projects in Paris in September 2008. A joint Japan-U.S. workshop is planned for October 2008.

d) LSN's Joint Engineering Team (JET) provides a forum for the development of operational policies and practices, including security policies and responding to security incidents, on the international science networks.

e) New techniques for inter-domain signaling developed under the NSF-supported DRAGON project are enabling a new networking paradigm—hybrid networking—that combines shared IP services with dedicated high-capacity capabilities for data-intensive scientific research. The U.S. academic community's Internet2 consortium is deploying the Dynamic Circuit Networking (DCN) service and ensuring international inter-operability through active collaboration with a peer network in Europe called GEANT.

f) To harmonize deployment of Internet Protocol version 6 (IPv6) in Federal networks with existing international programs, specifically the IPv6 Ready Logo program, NIST has signed Memoranda of Understanding for cooperative development of test materials with members of the IPv6 Forum. Forum members include: Yokogawa Electric Corporation of Japan, NTT Corporation of Japan, NTT Advanced Technology Corporation of Japan, Yaskawa Information Systems Corporation of Japan, Institut National de Recherche en Informatique et en Automatique (INRIA) and the University of Rennes in France, as well as the Inter-operability Laboratory of New Hampshire.

These examples illustrate how individual NITRD networking activities are directly linked to the appropriate international counterparts. Through its strategic planning activities, the NITRD program will explore whether other organizations, such as the Organization for Economic Cooperation and Development (OECD) through its information and communication technologies activities, can provide mechanisms for addressing the broader international networking issues.

3) Software engineering

Software is pervasive in our digital world, underlying the operation of planes, ships, factories, and medical devices; and controlling critical infrastructure such as power grids and banking and financial systems. As these critical software applications become increasingly complex, the need for robust software science—theory, concepts, and methodology for creating, analyzing, and verifying software—has become a global challenge.

Current NITRD example:

The Verified Software Initiative (VSI), a long-term cooperative, international project directed at the scientific challenges of large-scale software verification. The VSI resulted from the first Verified Software: Theories, Tools, Experiments Conference (VSTTE) held in 2005 in Zurich as a response to Sir Tony Hoare's (Microsoft Research U.K.) *Grand Challenge* on the "verifying compiler," a vision of software produced with machine-verified guarantees of adherence to specified behavior. International working groups are in place and much work has been done, resulting in multiple

technologies now available to address the challenge. The second VSTTE conference will be held in Toronto in October 2008; agencies in NITRD's High Confidence Software and Systems (HCSS) coordinating group—including NASA, ONR, NSA, and NSF—are co-sponsors of the VSTTE conferences and/or the grand challenge technical activities, such as the Verification Grand Challenge. These activities also draw participants from Australia, Belgium, China, Denmark, France, Germany, India, Israel, Japan, Switzerland, and the United Kingdom.

This example illustrates how international cooperation can accelerate progress on some of the most difficult, and most pressing, NIT challenges of our time.

4) Embedded and cyber-physical systems

A modern automobile is an integrated cyber and physical system, relying on embedded IT to control engine functions, anti-lock braking, transmission, emissions reduction, vehicle stability, and entertainment and climate control systems. Embedded NIT systems in planes, trains, ships, traffic control systems, and emergency response networks are an essential part of our everyday experience. Ensuring that these cyber-physical systems, are safe, effective, predictable, and reliable is another key global challenge.

Current NITRD example:

The High Confidence Software and Systems (HCSS) Coordinating Group within the NITRD Program has a strong focus on cyber-physical systems. Recent workshops sponsored by HCSS agencies in this area include high-confidence medical devices and systems and automotive safety. The HCSS group is also active in the international arena, participating in events such as the Cyber-Physical Systems (CPS) Week at the annual multi-conference (Real-Time and Embedded Technology and Applications Symposium [RTAS], International Conference on Information Processing in Sensor Networking [IPSN], and International Conference on Hybrid Systems [HSCC]) jointly sponsored by IEEE and the Association for Computing Machinery (ACM) and the upcoming Embedded Systems Week (International Conference on Embedded [EMSOFT], International Conference on Compilers, Architecture, and Synthesis for Embedded Systems [CASES], and International Conference on Hardware/Software Co-design and System Synthesis [CODES+ISSS]) jointly sponsored by the IEEE, ACM, and the Council on Electronic Design Automation. In the past month, a jointly-sponsored U.S./Japan workshop focused on human-robot interactions, emergency robotics, and medical robotics generated considerable enthusiasm for the potential for collaboration among investigators.

In summary, the HCSS group is developing both a national and international coordination effort in the area of cyber-physical systems.

Q2. Do you have suggestions for how the U.S. could institute a public-private research partnership to advance the capabilities of cyber-physical systems analogous to the EU's ARTEMIS initiative? Could such an undertaking be planned and carried out under the NITRD program?

A2. Certain elements of the ARTEMIS model are uniquely shaped by its European Union context. A model launched in the U.S. is SEMATECH (SEmiconductor MAnufacturing TECHnology). This broad industry consortium, which celebrated its 20th anniversary in 2007, began with close partnerships with the Sandia and Oak Ridge national laboratories. It is credited with restoring U.S. leadership in the industry. Thus, public-private partnerships can have a deep and lasting impact on the NIT landscape. The following examples, including one from outside the NITRD Program, may suggest some possible starting points for new, partnered initiatives.

Current NITRD examples:

a) In addition to federal agency networking organizations, the NITRD/LSN's Joint Engineering Team includes Internet2 and National LambdaRail (NLR) (both consortia of university network organizations), along with commercial entities such as Cisco, Juniper, and Sun.

b) LSN's Middleware And Grid Infrastructure Coordination (MAGIC) Team includes representation among public and private science networking organizations to provide inter-operability among grid infrastructures (Open Science Grid, Open Grid Forum), regional and local grid organizations, university grid capabilities through Educause, and commercial-sector participants such as Microsoft, IBM, and HP.

c) NSF's Industry & University Cooperative Research Program (I/UCRC) fosters partnerships between academic institutions, government agencies, national laboratories, and industry, including IT-related research centers reported in the NITRD crosscut. (For a complete list, see (*http://www.nsf.gov/eng/iip/iucrc/*). NSF's Cluster Exploratory (CluE) initiative has launched two industry-academia-government partnerships—one involving IBM and Google, the other HP, Intel, and Yahoo!—to provide researchers access to cluster computing resources.

d) Since 2005, NITRD's HCSS agencies have been sponsoring a national workshop series on key domains for cyber-physical systems (e.g., medical systems and devices, aerospace and transportation, critical-infrastructure and industrial-process control systems). This series is expressly designed to bring together public- and private-sector domain experts, researchers, developers, vendors, and users to share their perspectives and forge a common understanding on research and user needs in these vitally important technologies. These emerging communities of interest could possibly serve as a basis for a more formal partnership activity.

Related non-NITRD example:

In 2005, the Department of Energy, in collaboration with the Department of Homeland Security and Natural Resources Canada, partnered with industry leaders in the electric, oil, and natural gas sectors to design a unified framework to guide control-system cyber security R&D efforts and investment. The resulting 10-year Roadmap to Secure Control Systems in the Energy Sector was published in January 2006. The newly formed Energy Sector Control Systems Working Group composed of public and private energy-sector leaders, has been active in Roadmap implementation.

The SEMATECH example illustrates how an initial public-private partnership focused on a critical NIT challenge can produce a successful outcome. One of the largest technical challenges in computing currently is how to design software that can effectively use multicore systems. The PCAST cited the emergence of multicore processors in its rationale for recommending that: "the NITRD Subcommittee should facilitate efforts by leaders from academia, industry, and government to identify the critical issues in software design and development and help guide planning on software R&D."

NITRD agencies report the following recent initiatives in this area: Intel has partnered with academia to open two new scalable software research centers; DOD and DOE/SC have partnered with Goodyear and Caterpillar to develop a new set of geometry and messing tools—the foundation components needed to support fast problem solving on multiple cores; and the Council on Competitiveness is working with industry and NITRD agencies to organize a consortium for development of scalable engineering applications. Scalable software may be an area in which a significant level of shared public-private investment could spearhead technical innovation that would benefit the U.S. economy as a whole.

Q3. The COMPETES Act requires the NITRD program to develop and maintain a research, development and deployment roadmap for high-end computing systems. What steps are being taken and what is the timing for implementing this requirement?

A3. The NITRD Program is currently in the fourth year of the five-year plan set forth in the May 2004 *Federal Plan for High-End Computing* developed by an interagency task force at the request of the Office of Science and Technology Policy. Accomplishments to date achieved by the NITRD agencies as called for in that Plan include: development of leadership-class capability HEC systems; making cycles on those systems available to the broader private-sector research community for cutting-edge computational R&D projects; revitalization of R&D in HEC systems software through the HEC–University Research Activity HEC–URA); and collaboration on methods to streamline federal procurements and develop system bench-marking and evaluation tools that specifically address federal requirements.

Under the NITRD strategic planning process, all of the Program's research areas including HEC will develop new research plans and technical roadmaps coordinated with the overall vision laid out in the NITRD Strategic Plan. The timeline for these activities is presented in Appendix 3 of my written testimony.

Q4. One of PCAST's recommendations is for the NITRD National Coordination Office (NCO) to be more proactive in communicating with outside groups. Was this a fair criticism of the NCO and do you intend to make any changes related to the recommendation?

A4. We do not view the PCAST's recommendation as a criticism. It acknowledges the reality that the NCO must keep evolving in tandem with the evolution and maturation of the NITRD enterprise as a whole; PCAST has provided an opportunity for us to accelerate our efforts in a direction we were already headed. I've mentioned NCO-supported outreach efforts through the LSN teams and the HCSS workshop series. Another strong example is the monthly Expedition Workshop series co-sponsored by NITRD's SEW Coordinating Group. These workshops supported by NCO draw upwards of 100 participants spanning government, academia, and industry in an ongoing dialogue about ways to harness emerging technologies to improve public and private services for citizens. It is notable, for example, that the workshops have spawned more than a dozen professional Communities of Practice across the Federal Government, several of which have developed data standards adopted by the Office of Management and Budget under the Federal Enterprise Architecture. An automated emergency alert technology incubated in the workshops won OMB's Federal Innovation of the Year award.

The R&D coordination responsibility assigned to NITRD under the Comprehensive National Cybersecurity Initiative (CNCI) has at its core outreach to and close partnerships with the private sector. To accelerate the advance of new cyber security technologies toward commercial implementation, as called for under CNCI, the NCO must work aggressively to help agencies forge innovative working relationships with private-sector researchers, developers, vendors, and technology users. We have already taken key outreach steps, including having NCO staff schedule meetings with industry officials during office travel, and contacting industry representatives to participate in forthcoming high-level brainstorming sessions with federal cyber security managers.

It is my expectation that the NITRD Program's strategic planning process itself will identify additional opportunities for private-sector outreach. Several outreach efforts—a request for public inputs, a web site for public discussion of these inputs, and a national workshop—are already incorporated into our activities to develop the Strategic Plan for NITRD. In addition, I anticipate that the parallel strategic plan we will develop for the NCO, as called for by the PCAST, will specifically address new forms of NCO outreach activity in support of the NITRD Strategic Plan.

Q5. Dr. Stewart described examples of collaborative distance education to provide computer science related courses to students at institutions that may not have strong programs in this field as one way to attract more students to information technology careers. He suggests increased support for such programs could be particularly valuable in increasing the number of information technology professionals from under-represented groups. To what extent are such collaborative distance education programs now supported under the NITRD program, and are there any impediments to increased funding for such activities?

A5. While broad implementation of education delivery systems lies outside the NITRD Program's core mission, the R&D activities under the program have resulted in many of the technologies and resources that enable distance-education, supported research in best practices and approaches, and examined the social and behavioral implications of remote learning and virtual interaction. The NITRD Program and its predecessors have been the vanguard of the technological revolution that made distance learning possible and that continues to enrich its capabilities. The NITRD agencies including DARPA, NASA, NIH/NLM, and NSF (as well as the Library of Congress and the National Endowment for the Humanities) played a lead role in developing the enabling technologies for the concept of digital libraries and supporting the creation of the first generation of major digital collections of human knowledge and artifacts. Today, we take for granted that written works, art, and historical artifacts are accessible to us online; in 1994, when the NITRD agencies initiated their digital libraries activities, such access was a dream.

Examples of technologies applied in distance learning that originated in NITRD research include: modeling and simulation of experimental data; haptic devices for remote manipulation of instruments and visualizations; the Visible Human series of images of the human body; multi-modal computer interfaces and interactive devices; hyperwall technologies; grid technologies, applications, and services; and wireless, hybrid, and all-optical networking technologies, to name only a few.

The National Science Foundation—with its broad mission of support for STEM education as well as for academic science and engineering research—sponsors an array of formal distance-learning activities, including projects reported under the NITRD crosscut. Under a recent NSF award to the University of Houston, Downtown, The American Indian Higher Education Consortium (AIHEC), the Hispanic Association of Colleges and Universities (HACU), and the National Association for Equal Opportunity in Higher Education (NAFEO) propose to establish the Minority

Serving Institutions (MSI)-Cyberinfrastructure (CI) Empowerment Coalition (MSI–CIEC) to foster a CI-enabled distributed education and research network providing e-science education and research opportunities to MSI faculty and students. MSI–CIEC will provide the "human middleware"—the social and technological mechanisms facilitating the necessary communication and support linkages between MSI faculty and students, and researchers associated with e-science and CI initiatives.

NIH supports professional distance learning through the National Library of Medicine's (NLM's) PubMed and Medline digital archives as well as through a growing assortment of biomedical image and data collections and networks for sharing such information. The NLM also supports experiments and training in telemedicine applications. The NIH Office of Science Education provides online resources for educators, an e-mentoring program for high school and college students, and career-planning materials.

NSA and NSF are partnering with other funders in a North Carolina program with distance-learning components that are applied to help support exceptional K–12 teachers in STEM improve their curricula by working with higher-education faculty and researchers. Through the Kenan Fellows Program (KFP) for Curriculum and Leadership Development, the competitively selected teachers spend two years conducting experiments with researchers and developing new curriculum ideas and techniques based on their work.

Non-NITRD examples:

Though not part of the NITRD crosscut, NASA operates what is perhaps the Federal Government's most vibrant distance-learning activity, in that the agency has incorporated outreach by means of advanced digital technologies into its real-time explorations of Earth and space, including vast archives of scientific images and broadcasts from space. Microsoft's WorldWide Telescope and Google Sky are innovative tools for experiential learning enabled by the data resources of the Sloan Digital Sky Survey, the Hubble Space telescope, the Wilkinson Microwave Anisotropy Probe, and the IRAS (infrared), Chandra (x-ray) and GALEX (ultraviolet) missions.

Although it is not part of the NITRD crosscut, the Information Resources Management College of DOD's National Defense University offers 50 graduate-level courses that can be taken in a "distributed learning" format. These courses focus on various aspects of information technology leadership leading to certificates for CIO, including: Information Assurance, IT Project Management, Organizational Transformation, and Enterprise Architecture. These courses are available to Federal, State, and local government employees who are college graduates, and to government contractors. This provides an excellent example of how the NITRD agencies are using distance learning capabilities to meet their own education and training needs.

As noted in my written testimony, we are incorporating education issues in the NITRD strategic planning process, and have initiated a fast-track study of NIT education as recommended by PCAST. In addition, NITRD's SEW Coordinating Group will hold a workshop September 16, 2008 to bring together representatives of Federal agencies, including non-NITRD agencies, with responsibilities in the education arena. The workshop will focus on both the role of NIT in education and NIT workforce needs for the future. This meeting is intended to kick off an ongoing education activity under NITRD's strategic planning process.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Daniel A. Reed, Director, Scalable and Multicore Computing, Microsoft Corporation

Questions submitted by Chairman Bart Gordon

Q1. Are there areas of IT research that are good candidates for international cooperative efforts that would leverage U.S. investments but would not otherwise harm U.S. competitive advantages, such as being first to market for a new technology? What mechanisms are available, or could be instituted, to facilitate such international cooperative research?

A1. This is an extraordinarily complex problem, given the global nature of information technology and the role that U.S. multinational computing companies play around the world. As with all technologies, one must chose carefully, leveraging the intellectual value of international collaboration, while avoiding the loss of competitive advantage in the U.S.

In an increasingly competitive environment, it is unlikely, however, that the U.S. will maintain intellectual leadership in all areas of computing. Thus, in certain areas, it is in our interests to collaborate. For example, the European Union is now highly competitive with the United States on formal verification and embedded systems research.

In addition to specific technology areas, one might focus on the applications of computing to international problems, climate change, the environment and global health and nutrition. In these domains, there are many computing research challenges, including data management and mining, software and computer architecture. This is just one area where international collaboration might benefit the U.S.

Regardless of the chosen areas, one must remember that the benefits from research accrue disproportionately to the Nation in which that research is performed. Because information, such as advancements in basic science, is most easily communicated through interpersonal interactions, having those interactions occur within our borders makes it much more likely that U.S. industry will capitalize on those advancements.

Q2. Do you have suggestions for how the U.S. could institute a public-private research partnership to advance the capabilities of cyber-physical systems analogous to the EU's ARTEMIS initiative? Could such an undertaking be planned and carried out under the NITRD program?

A2. Yes, such an undertaking is possible. ARTEMIS is structured around the European Union R&D processes, with much tighter academic and industry collaboration than is typical in the U.S. To be globally competitive, I believe the U.S. must reconsider some of the ways industry-academic collaborations are currently structured and reassess the reward metrics and associated intellectual property mechanisms.

Moreover, industrial-academic partnerships in U.S. have often been difficult given the financial focus on quarterly returns. We must restructure the compact among the parties in a way that industry invests in an appropriate share of long-term research. Microsoft, for example, is investing aggressively in long-term research, both via Microsoft Research and via external funding to academic partners.

Cyber-physical systems span a broad spectrum, from national and international infrastructure to home heating and cooling controls, and would be a candidate for this type of partnership. This is an area where opportunities might be best identified by a series of focused, government-academe-industry workshops. The NITRD program would be best served by picking one or two target areas that could be defined clearly and focused on removing programmatic impediments to success.

Q3. Are the R&D objectives of the NITRD program, as it is currently constituted prioritized appropriated and is the allocation of funding consistent with achieving the objectives? Are there particular research areas that the NITRD program is not pursuing with sufficient resources?

A3. No, not at present. We must increase investment in software and cyber-physical systems (see below), even if it means decreasing funding in some other areas.

In addition to software, we need better tools for managing the explosive growth of computer-generated data. The era of the personal petabytes is very near, and our mechanisms for ensuring long-term data preservation, security and privacy are ill-suited to today's data volumes, much less those expected in the future. Moreover, extracting insight from such large volumes of distributed data remains extraordinary difficult.

Finally, and perhaps most importantly, we must take a systemic, scalable approach to integrated computing challenges. Many, arguably most, of the computing R&D challenges require multi-disciplinary teams of computing researchers—computer architects, hardware designers, system software researchers, network visionaries, programming model and tool experts, data mining and management researchers, and domain experts.

Our current research ecosystem makes it difficult to both assemble such teams and to sustain them long enough to mount explorations of systemic challenges. It was for this reason that the 1999 PITAC report recommended funding large-scale, revolutionary explorations—*Expeditions to the 21st Century.* Such explorations, involving academe, government and industry, are a missing element of our research ecosystem and would go far to rebalance the risk-reward portfolio of the NITRD program in favor of more long-term, high-risk research.

Q4. The President's Council of Advisors on Science and Technology (PCAST) recommends that the NITRD program provide increased support for research on software but does not cite specific research needs where the current program is deficient. Do you have recommendations for how the NITRD's investment in software research could be strengthened, assuming no substantial increases in overall funding?

A4. There are at least four major software challenges before us today; each is equally important.

I. *Reliability and correctness of large software systems.* Much of our critical national infrastructure and our daily lives depend on software systems—our financial markets, communication systems, electrical power grid, transportation infrastructure, signals intelligence, commercial web services and enterprise software. Our lives and even our identities are dependent on software systems that manage information and infrastructure on our behalf, yet we do not have good methods to ensure the reliability of these systems or to design them to operate correctly—on time and on budget.

II. *Cyber-physical system software models and tools.* In some sense, cyber-physical systems are a special case of the first challenge, albeit with greater coupling of sensors, actuators and communication via wired and wireless networks. From an implanted pacemaker to the electronic fuel injection and anti-skid brakes in today's automobiles though avionics in a military or commercial jet, cyber-physical systems touch us minute-by-minute. These distributed systems are ubiquitous, because their advantages are manifold, but also difficult to design and validate, given their complexity and the interdependence among disparate components. Moreover, failure of one system component can have far-reaching and often disastrous consequences. (Consider, for example, the global effects of a single design failure in a commercial jet's avionics system.)

III. Security, privacy and resilience in an uncertain world. Almost all of our critical data—personal, corporate and government—reside in distributed data systems and networks. Many of these systems are vulnerable to cyber attacks and to malicious behavior. We must develop tools and techniques to design more resilient systems, and ones that are provably secure.

IV. *Efficient and easy-to-use tools for multicore programming.* For over thirty years, we have been the beneficiaries of a virtuous cycle of new and richer computing systems, powered by ever faster microprocessors. Each new generation of processors executed old software faster and enabled new capabilities—graphical interfaces, speech recognition systems and mobile devices.

Today, device power limits are forcing a new approach to chip design—placing multiple processors on each chip. Such multicore systems pose daunting challenges for software development, requiring parallel programming to deliver high performance on new applications. However, we lack the necessary tools that would enable software developers to exploit these multicore processors easily and effectively. This multicore programming crisis is one of the deepest facing the commercial software industry today, and inadequate research investment in years past is one of our current problems.

Unless we find solutions to these problems—and soon—not only will we risk catastrophic failure of critical national infrastructure, the virtuous cycle of hardware-software innovation that has driven the computing industry will be threatened. Some of these, such as ensuring correctness and reliability in large, complex soft-

ware systems, are longstanding. Others, such as multicore programming, are more recent.

In a fixed budget scenario, we must reallocate funds from other, lower priority R&D activities and better manage and coordinate extant investments to increase efficiencies by eliminating redundant activities.

Q5. Does the research community—both academe and industry—have a voice in influencing the research priorities under the NITRD program? Are improvements needed in the external advisory process for the NITRD program?

A5. Yes, but not a fully effective voice. Academe influences research priorities via workshops and joint meetings with the NITRD program agencies, but the relative investments in specific technical agendas are more often driven by agency needs than by community priorities. The NSF, as a research agency, is perhaps the most responsive to community priorities but even there proposals for specific budget allocations are rarely discussed with the community.

On the industry side, there are fewer mechanisms for community engagement with NITRD agencies. In general, industry trade associations tend to represent short-term issues, rather than the basic research topics central to the NITRD portfolio. Individual companies do engage, but do so carefully lest they be viewed as advancing parochial interests.

I believe we must have greater coordination across the government-academic-industry partnership. Our international competitors recognize the critical importance of such partnerships. We cannot afford to continue to treat the three partners as arms-length collaborators. Hence, we need much more than pro forma workshops and meetings which "rubber stamp" extant agendas if we are to maintain our competitive position. We also need to find new ways for collaborative technical partnerships across government, academe and industry, including honest assessments of intellectual property issues.

PCAST recommended that the NITRD program increase its strategic planning and define roadmaps for realizing the strategic plans. These planning exercises, together with public assessments of progress against the plans, would be an ideal mechanism to engage academe and industry to regularly scheduled assessments and recommendations.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Craig A. Stewart, Chair, Coalition for Academic Scientific Computing; Associate Dean, Research Technologies, Indiana University

Note: these responses are presented by Dr. Stewart on behalf of CASC. These responses have been endorsed by a majority vote of CASC members, without dissensions.

Questions submitted by Chairman Bart Gordon

Q1. Are there areas of IT research that are good candidates for international cooperative efforts that would leverage U.S. investments but would not otherwise harm U.S. competitive advantages, such as being first to market for a new technology? What mechanisms are available, or could be instituted, to facilitate such international cooperative research?

A1. As a general approach to networking and information technology, CASC recommends focusing on international collaboration efforts that will set standards for inter-operability. Examples include standards set by the Open Grid Forum (*http://www.ogf.org/*) for grid computing and international standards for networking. Over the next several years, two areas should be priorities:

- Advanced optical networking standards and techniques for high-bandwidth connections (e.g., greater than 40 gigabits per second), techniques for dynamic creation of dedicated networks in support of virtual organizations, and development of sensor networks for environmental and resource monitoring.
- Identity management—particularly creation of national online identity management systems for research cyberinfrastructures, and the creation of international trust relationships between such systems where appropriate. This would greatly facilitate international collaboration across many areas of science and technology. One example would be establishing InCommon (*http://www.incommonfederation.org/*) as the definitive U.S. credential management system for research IT (as CASC has previously recommended).

Such efforts might be funded via international collaboration of U.S. federal funding agencies and the European Union Research Framework Programme (*http://cordis.europa.eu/fp7/home_en.html*). A joint call with issues by the U.S. and the EU Research Framework Programme, and joint funding, would be a highly effective way to promote international collaboration in networking and information technology.

The creation of internationally accepted standards for inter-operability of networking and information technology systems is essential to the U.S. and to its ability to cooperate internationally. We believe that the U.S. then competes by developing the best implementations of information technology, the most effective cyber-physical systems, and the most effective interaction of simulation via computer and verification through experimentation. In this way the U.S. can collaborate when appropriate, and compete (and win) when competing is appropriate.

Q2. Do you have suggestions for how the U.S. could institute a public-private research partnership to advance the capabilities of cyber-physical systems analogous to the EU's ARTEMIS initiative? Could such an initiative be planned and carried out under the NITRD program?

A2. The ARTEMIS initiative is an excellent model, and establishing a partnership based precisely on this model could and should be carried out under the NITRD program. A critical element for success of such a program in the U.S. would be to fund time for U.S. academic researchers to work as part of such collaborative efforts. The most valuable commodity brought to private-public partnerships is the time of the public sector experts and researchers. U.S. university and college technology transfer offices tend to focus on intellectual property outcomes resulting from collaborative research before such research is even initiated. These negotiations are a significant obstacle to public-private collaboration. This situation arises in part as a result of the interpretations of the *Bayh-Dole Act.* For a public-private partnership modeled on ARTEMIS to be most effective, it might be helpful to include specific terms in a solicitation (with, if needed, accompanying legislation) that facilitates partnership and innovation by establishing clear guidelines for technology transfer to the private sector and rights to and payment for same.

Q3. Are the R&D objectives of the NITRD program, as it is currently constituted, prioritized appropriately and is the allocation of funding consistent with achiev-

ing the objectives? Are their particular research areas that the NITRD program is not pursuing with sufficient resources?

A3. The prioritization recommended in the PCAST report is, overall, appropriate. (I note that in the written testimony CASC added increased focus on complexity-hiding interfaces such as Science Gateways as a new area for emphasis that has come to the fore since the PCAST report).

However, the objectives set forth in the PCAST recommendations cannot be carried out effectively, in ways that preserve U.S. international competitiveness, without substantial increases in the NITRD budget.

CASC recommends a significant increase in the NITRD budget, with focus particularly on three areas:

- Creation of a national research cyberinfrastructure as an interagency activity. Such a national cyberinfrastructure should have significantly greater capability than the aggregate of the various federal agency initiatives. We echo and support particularly Dr. Reed's testimony on the point of interagency funding balance. Because there are multiple large-scale cyberinfrastructure efforts, and because none of the cyberinfrastructure systems are yet straightforward enough for most researchers to use, the number of researchers currently using such advanced facilities is in the low tens of thousands. U.S. global competitiveness would be best supported if hundreds of thousands of researchers could use these facilities.
- Rebalancing the NITRD budget so that a relatively greater fraction of overall funding is devoted to software development. Three areas stand out in particular: development of parallel programming tools and applications for multicore processors; hardening and sustainability of software critical to the Nation's research; and funding for the creation of complexity-hiding interfaces such as Science Gateways. Because most existing software does not efficiently exploit the power of multicore processors, and because there is insufficient funding for development of new multicore programming tools and applications, much of the power of multicore processors goes unexploited in computing systems ranging from laptops to the largest supercomputers. Because there is insufficient funding for hardening of innovative software, and its maintenance as a general tool for public sector research, much innovative and useful software is not as widely (or as long) used as it could or should be. And the lack of sufficient funding for the development of complexity-hiding interfaces is one of the primary factors behind the difficulty U.S. researchers have in using current NITRD-funded cyberinfrastructure. U.S. research competitiveness suffers as a result of all of these factors.
- Increased attention to training and development of the next generation of researchers and programmers. We note in particular that parallel computing—one of the most difficult forms of computing for programmers to master—has migrated from what was once a tiny niche of the computing market into the overwhelming majority of computing systems, from mainframes to laptops, and soon into cell phones as well. At colleges and universities worldwide, computer science departments are uncovering serious deficiencies in their ability to teach parallel computing. Because of lack of training, there is more important work to be done than there are researchers and programmers available in the U.S. to do it. That means that important work is either not done at all or is done outside the U.S.

I note that it is likely rare that any concerned individual or group representative appears before Congress and states "the area in which we work receives too much money" or even "the area in which we work is properly funded." CASC's recommendation for an increase in the NITRD program is not intended to be self-serving, however. The areas in which increased funding is most critically needed (expanded national cyberinfrastructure, and even greater expansion in funding for software and education and training) are needed so that the networking and information technology can better serve the other U.S. communities and research disciplines. The need is severe as well. The funding needed to ensure U.S. leadership in networking and information technology innovation, and the application of these innovations in ways that maintain U.S. global leadership, is not a few percentage points but rather on the order of hundreds of millions of dollars. We recognize that there are many pressures on the federal budget. Maintaining U.S. global leadership in networking and information technology is essential to the long-term U.S. security and prosperity. Increased investment is essential now.

Q4. The President's council of Advisors on Science and Technology (PCAST) recommends that the NITRD program provide increased support for research on software but does not cite specific research needs where the current program is deficient. Do you have recommendations for how the NITRD's investments in software research could be strengthened, assuming no substantial increases in overall funding?

A4. Let me begin by reiterating the point made in response to an earlier question: the objectives set forth in the PCAST recommendations cannot be carried out effectively, in ways that preserve U.S. international competitiveness, without substantial increases in the NITRD budget.

Having said that, CASC suggests that the following specific areas of software research are currently inadequate and should be particularly strengthened:

- Programming languages, compilers, run-time environments, and performance analysis and management tools, particularly for parallel computing using multicore processors.
- Complexity-hiding interfaces, such as Science Gateways, so that the benefits of advanced networking and information technology systems may be more easily used by the U.S. science and engineering communities.
- Software for management and analysis of massive data sets and real time data streams, including automated metadata creation, provenance management, and real time analytic and visual analysis tools.
- For advanced simulation and prediction software, increased funding for interdisciplinary research that will test simulations and predictions against real life phenomena and improve software accuracy and validity as a result.
- Across all areas of software research, funding for the transformation of innovative software into software that is robust, widely usable, well supported, and maintained over time. This recommendation echoes my testimony on the point of consistency in funding streams over time and its importance in preserving the human capital and expertise required to keep software useful over time. Within the trio of research, development, and delivery, U.S. competitiveness in the future will be critically dependent upon more funding for development and delivery.

Q5. Does the research community—both academe and industry—have a voice in influencing the research priorities under the NITRD program? Are improvements needed in the external advisory process for the NITRD program?

A5. The Committee on Science and Technology's hearing of 31 July was an excellent opportunity for the research community to comment on the priorities of the NITRD program, and we very much appreciate that opportunity.

The research community has a voice, particularly through PCAST, but it is a voice that is less focused on networking and information technology—and thus less strong—than during the tenure of the President's Information Technology Advisory Committee. We thus recommend the re-creation of a President's Information Technology Advisory Committee to add to the advisory input that is currently heard via the excellent work of PCAST.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Don C. Winter, Vice President, Engineering and Information Technology, Phantom Works, the Boeing Company

Questions submitted by Chairman Bart Gordon

Q1. Are there areas of IT research that are good candidates for international cooperative efforts that would leverage U.S. investments but would not otherwise harm U.S. competitive advantages, such as being first to market for a new technology? What mechanisms are available, or could be instituted, to facilitate such international cooperative research?

A1. We believe that there are several areas that would be good candidates. The areas of High End Computing Infrastructure and Applications (HEC l&A). High End Computing R&D, Human Computer Interactions and Information Management (HCI & IM), and Large Scale Networking (LSN) are good candidates for international cooperative efforts. They are rich in pre-competitive research challenges and offer substantial leverage opportunities and potentially significant cost savings. International cooperative research might be facilitated through the creation of joint projects addressing "grand challenges." Targeted expenditures for international collaboration are already in-place at NSF—however, we are not aware of metrics that enable us to assess the leverage or potential cost savings to development programs of these collaborations.

Q2. Do you have suggestions for how the U.S. could institute a public-private research partnership to advance the capabilities of cyber-physical systems analogous to the EU's ARTEMIS initiative? Could such an undertaking be planned and carried out under the NITRD program?

A2. We believe that this could be achieved by creating Industry/University Consortia to perform pre-competitive research on industry-provided testbeds. The "industrial strength" fidelity of the testbeds is critical to ensuring that the research focuses on the highest payback elements of the problem space of cyber-physical systems. Consortia focused on more applied levels have been highly successful and include USCAR (U.S. Council for Automotive Research) and AVSI (Aerospace Vehicle Systems Institute).

Fundimg for the consortia could be assembled from: 1) Industry: Internal Research & Development; 2) Academia: Government; 3) Testbed—Government.

We propose a model based upon joint work of integrated projects as opposed to loose/spontaneous collaborations. While the latter model can sometimes produce important benefits, we believe the focus needs to be the synergistic development of fundamental science directly motivated and evaluated on realistic challenge problems from industry. In this rapidly evolving field where time and resources are limited, this is the most effective way to build a core technology base. Knowledge and technology is best transitioned by people working on well defined problems using industrial strength testbeds.

While it is possible that this activity could be carried out under NITRD, it is not clear that there are existing mechanisms for accomplishing this. From our perspective, a task force consisting of representatives from industry and academia should be created to examine potential models, and recommend the appropriate structure within the next 90 days. A further recommendation is that task force leadership should be provided by industry to emphasize the need to consider novel organizational and execution models.

Q3. Are the R&D objectives of the NITRD program, as it is currently constituted, prioritized appropriately and is the allocation of funding consistent with achieving the objectives? Are there particular research areas that the NITRD program is not pursuing with sufficient resources?

A3. From our perspective the R&D objectives, as indicated by funding levels, are not optimally prioritized. Nearly 50 percent of the FY 2008 and 2009 NITRD budgets ($1.5B out of $3.3B in FY08) are allocated to High End Computing (Architecture, Infrastructure, and R&D). HEC is not at present an area where we feel U.S. competitiveness is at stake. Expenditures for Human Computer Interaction and Information Management ($0.8B) also appear out of proportion relative to the need and potential gains in research and competitiveness to be attained. The PCAST correctly pointed out the need to substantially increase the level of spending on CPS—which is not even explicitly mentioned among the programs in NITRD budget documents.

We believe that CPS should be included as a separate program under NITRD since this would provide transparency of budget allocations to this critical technology area. Fundamental research progress in CPS will have long-term benefits to assuring competitive position in Aerospace, Automotive, Energy Management, Health and other areas. Furthermore, the low level of funding for High Confidence Software and Systems (HCSS) ($0.12B), and Software Design & Productivity (SDP) ($0.073B) do not adequately address the needs and challenges for CPS, and are insufficient to stimulate breakthroughs required, especially in large scale CPS systems common to DOD and commercial Aerospace and Energy applications.

We are also concerned about the isolation of Cyber Security and Information Assurance (CSIA) from the systems domains (HCI & IM, LSN, HCSS, SEW, SDP). CPS must include an essential CSIA program element because of the unique vulnerabilities and consequences associated with the target industries. What we need is CPS focused R&D in CSIA, tightly integrated with all other research challenges.

Q4. The President's Council of Advisors on Science and Technology (PCAST) recommends that the NITRD program provide increased support for research on software but does not specify research needs where the current program is deficient. Do you have recommendations for how the NITRD's investment in software research could he strengthened, assuming no substantial increases in overall funding?

A4. A number of workshops have been conducted since 2005, led by Dr. Andre Van Tilborg (Director of the Information Systems Directorate in the Office of the Deputy Under Secretary of Defense for Science and Technology) that sought Government, Industry, and Academic perspectives on Software Intensive Systems. The workshops highlighted the clear need and established a framework for a software research agenda. The aerospace industry in particular (Boeing, Lockheed, Raytheon, Northrop, BAE, Honeywell, among others) presented a common perspective on the need and benefits of testbed driven software research. Elements of the research agenda are published in a study on Ultra Large Scale Systems. While the total level of NITRD investment may be adequate, funds should be shifted from HEC and HCI & IM to CPS focused investments in HCSS, Cyber Security, and Software Design due to its significantly larger impact on U.S. competitiveness. In addition, increased investment in these areas holds significant potential for reducing costs for DOD CPS software developments.

Q5. Does the research community—both academe and industry—have a voice in influencing the research priorities under the NITRD program? Are improvements needed in the external advisory process for the NITRD program?

A5. Industry has had a very limited voice in influencing research priorities of NITRD program. Organizations like PCAST have influence at a strategic level but they have little influence in implementation. We believe that proactive industrial participation in shaping NITRD priorities and participation in the research agenda is key to achieving breakthroughs required.

Q6. The top recommendation of the PCAST assessment of the NITRD program for new research investments is in the area of cyber-physical systems. You have been engaged with your colleagues from industry, academia, and government in discussions of research requirements in this field. What is the status of these discussions? Are there plans to develop a set of research goals and a roadmap for achieving these goals?

A6. The discussions on research requirements continue. Under the auspices of the aforementioned workshops, we have formed industry teams in aerospace, energy management, and automotive and are working to finalize technology roadmaps. The discussions were initiated in May 2007 at a CPS roundtable conducted with representatives from industry (BAE, Boeing, Lockheed, Honeywell, United Technology, IBM, etc.). Academia (Carnegie Mellon, UCB, Vanderbilt, etc.), and Government (NSF, DOD, etc.). We have developed initial industrial roadmaps that need to be finalized and then shared with the research community at large.

Q7. What do you see as the relative roles of industry-sponsored research and federally-sponsored research in moving this technology area forward and giving the U.S. a strong position?

A7. The major issue here is that the CPS research agenda is cross-cutting and spans multiple industries. Much of the research required is of a pre-competitive nature—where industry-sponsored research dollars are inherently limited. The current approach of Federal Government-sponsored research in this area has not adequately

addressed “industrial strength” real-world challenge problems, and not created significant transition pathways outside of the academic world. Greater industrial participation in executing the research agenda is critical to success and will spur the focused industrial-academic collaboration needed for significant progress.